NASA GPM-Ground Validation

Integrated Precipitation and Hydrology Experiment 2014

Science Plan

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Summary

Ground validation (GV) campaigns before and after the launch of NASA's Global Precipitation Measurement Mission (GPM) Core satellite in early 2014 have been planned to collect targeted observations to support precipitation retrieval algorithm development, to improve the science of precipitation processes, and to demonstrate the utility of GPM data for operational hydrology and water resources applications. The Integrated Precipitation and Hydrology Experiment (IPHEx) centered in the Southern Appalachians and spanning into the Piedmont and Coastal Plain regions of North Carolina seeks to characterize warm season orographic precipitation regimes, and the relationship between precipitation regimes and hydrologic processes in regions of complex terrain. The IPHEx heritage stems from and also currently includes collaboration with the NOAA Hydrometeorological Testbed Southeast Pilot Studies Program (HMT-SEPS).

Since 2007, a high elevation tipping bucket rain gauge network has been in place in the Pigeon River Basin (PRB) in the Southern Appalachians and intensive observing periods (IOPs) have been conducted in this and surrounding river basins to characterize ridge-ridge and ridge-valley variability of precipitation using radiosondes, tethersondes, Micro-Rain Radars (MRRs), automatic weather stations and optical disdrometers. Important results from these analyses include the importance of light (<3 mm/hr) rainfall as a baseline freshwater input to the region especially in the cold season, and the high frequency of heavy rainfall and severe weather in the warm season, and illuminate the significant spatio-temporal variability of rainfall in this region.

IPHEX will consist of two activities: 1) an extended observing period (EOP) from October 2013 through October 2014 including a science-grade raingauge network of 60 stations, half of which will be equipped with multiple raingauge platforms, in addition to the fixed regional observing system; a disdrometer network consisting of twenty separate clusters; and two mobile profiling facilities including MRRs; and 2) an intense observing period (IOP) from May–July of 2014 post GPM launch focusing on 4D mapping of precipitation structure during which NASA's NPOL S-band scanning dual-polarization radar, the dual-frequency Ka-Ku, dual polarimetric, Doppler radar (D3R), four additional MRRs, and the NOAA NOXP radar) will be deployed in addition to the long-term fixed instrumentation. During the IOP, the NASA ER-2 and the UND Citation aircraft will be used to conduct high altitude and "in the column" measurements.

The ER-2 will be equipped with multi-frequency-radiometers (AMPR and CoSMIR), the HIWRAP Ka/Ku-band, CRS W-band, and EXRAD X-band radars. The ER-2 instrument

complement collectively functions as an expanded GPM Core “satellite proxy”. The UND Citation instruments will be dedicated to microphysical characterization. The ground-based instrumentation sites were selected to collect extensive samples of orographic effects on microphysical properties of precipitation, specifically DSDs, for the dominant warm season precipitation regimes in the region: 1) westerly systems including Mesoscale Convective Systems (MCSs) and fronts; 2) southerly and southeasterly convective systems and tropical storms; and 3) convection initiation and suppression and feeder-seeder interactions among fog and multilayered clouds in the inner mountain region. A real-time hydrologic forecasting testbed is planned to be operational during the IPHEX IOP. In preparation for the forecasting testbed, a benchmark project for intercomparison of hydrologic models has been developed (H4SE) in the context of which all data necessary (GIS, atmospheric forcing, land-surface attributes, soil properties, etc) to implement and operate hydrologic models in four major SE river basins (the Savannah, the Catawba-Sandee, the Yadkin-Peedee and the Upper Tennessee) were analyzed and processed at hourly time-step and at 1 km^2 resolution over a 5-year period (2007-2012) and will be extended through 2014. Data are currently available from http://iphex.pratt.duke.edu to all participants. The goal of H4SE is to facilitate implementation of hydrologic models in the IPHEX region to assess the use and improve the utility of satellite-based Quantitative Precipitation Estimates (QPE) for hydrologic applications.

In addition to the primary GPM IPHEx plan, three other monitoring activities will take place: 1) observations in support of aerosol-cloud-rainfall interactions including the chemical characterization of CCN, haze and fog and cloud microphysisc and vertical structure including optical properties; 2) intense measurements of soil moisture conditions over a wide range of heterogeneous land-use and land-cover fields concurrent with flights of the SLAP instrument; and 3) determination of groundwater transit times using trace gas analysis of streamflow samples.

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1. Introduction

1.1 Overview

The 2014 Integrated Precipitation and Hydrology Experiment (IPHEx) is a Ground Validation field campaign in support of the Global Precipitation Measurement (GPM) satellite mission sponsored by NASA's PMM (Precipitation Measurement Missions) Program. IPHEx will take place in the complex terrain region of Southern Appalachians with a principal core site in the Pigeon River Basin and a second site in the Upper Catawba watershed in collaboration with NOAA's HMT-SEPS (Hydrometeorological Testbed SE Pilot Study), and there will be an opportunity to leverage existing NSF, NOAA, USGS, NPS, EPA, and USCoE monitoring sites across the Piedmont and Coastal Plain (Fig. 1). GPM was launched February 27, 2014 (see http://www.nasa.gov/gpm), and IPHEx will be the first ground-validation campaign after launch. IPHEx is taking place in two phases: a long-term 1-year duration period collecting ground observations; and an intense Observing Period (IOP) from 5/1/2014 through 6/15/2014, which will include aircraft observations. IPHEX will leverage and augment existing long-term meteorological and hydrological monitoring systems already in place in the region to acquire comprehensive observational data to address GPM science needs.

The overarching goals of IPHEx are three-fold: 1) to improve the estimation of orographic precipitation in regions of complex terrain from space through improved understanding and observations; 2) to characterize the utility of satellite-based Quantitative Precipitation Estimates (QPE) for operational hydrological forecasts of floods and natural hazards at multiple scales; and 3) to characterize the uncertainty associated with QPE products for water resources and water cycle research and applications. The research strategy consists of three major tasks: 1) to conduct detailed science grade measurements of precipitation processes over one year to map the seasonality of the error structure of satellite-based precipitation estimates for various types of hydrometeorological regimes in the Southern Appalachians; 2) to conduct ground-and aircraft-based 4D observations of space-time evolution of the structure of warm season precipitation systems in the complex orography; and 3) to implement a testbed for the intercomparison of operational hydrology forecasting models and QPE in four major river basins in the SE US with headwaters in the Southern Appalachians using various models and QPE products (IPHEx-H4SE). The third task includes close collaboration with NOAA's Hydrometeorological Testbed Southeast Pilot (HMT-SEPS) activity as well as the engagement of NOAA's National Weather Service and regional stakeholders with operational missions in weather, hydrology and related applications. Finally, IPHEx will establish a repository of high quality observations and data sets to support scientific research and operational innovation and development beyond the completion of the planned tasks.

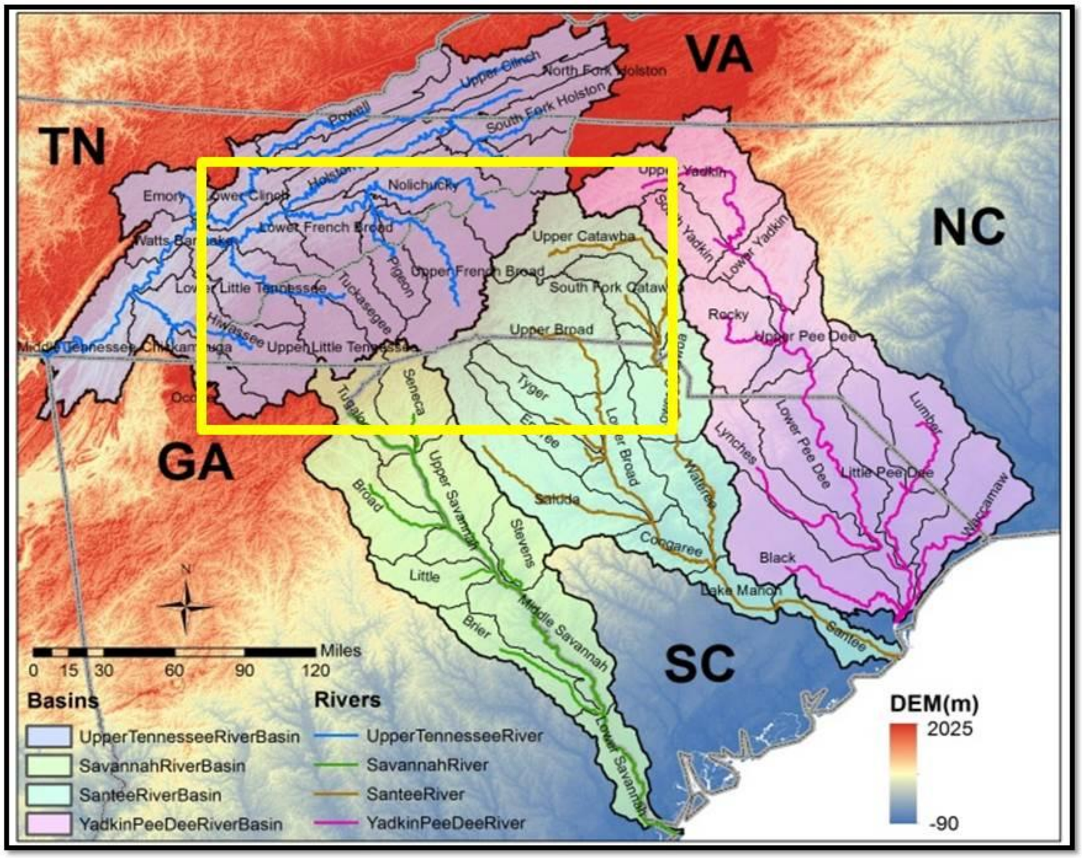


Figure 1 - Extended IPHEx domain (EID) with focal SE river basins delineated. In clockwise direction: Upper Tennessee (purple, 56,573 km^2), Yadkin-Peedee (pink, 46,310 km^2), Catwaba-Santee (blue, 39,862 km^2), and Savannah (green, 27,110 km2). The yellow rectangle denotes the Core Observing Area (COA) where ground validation efforst will be concentrated.

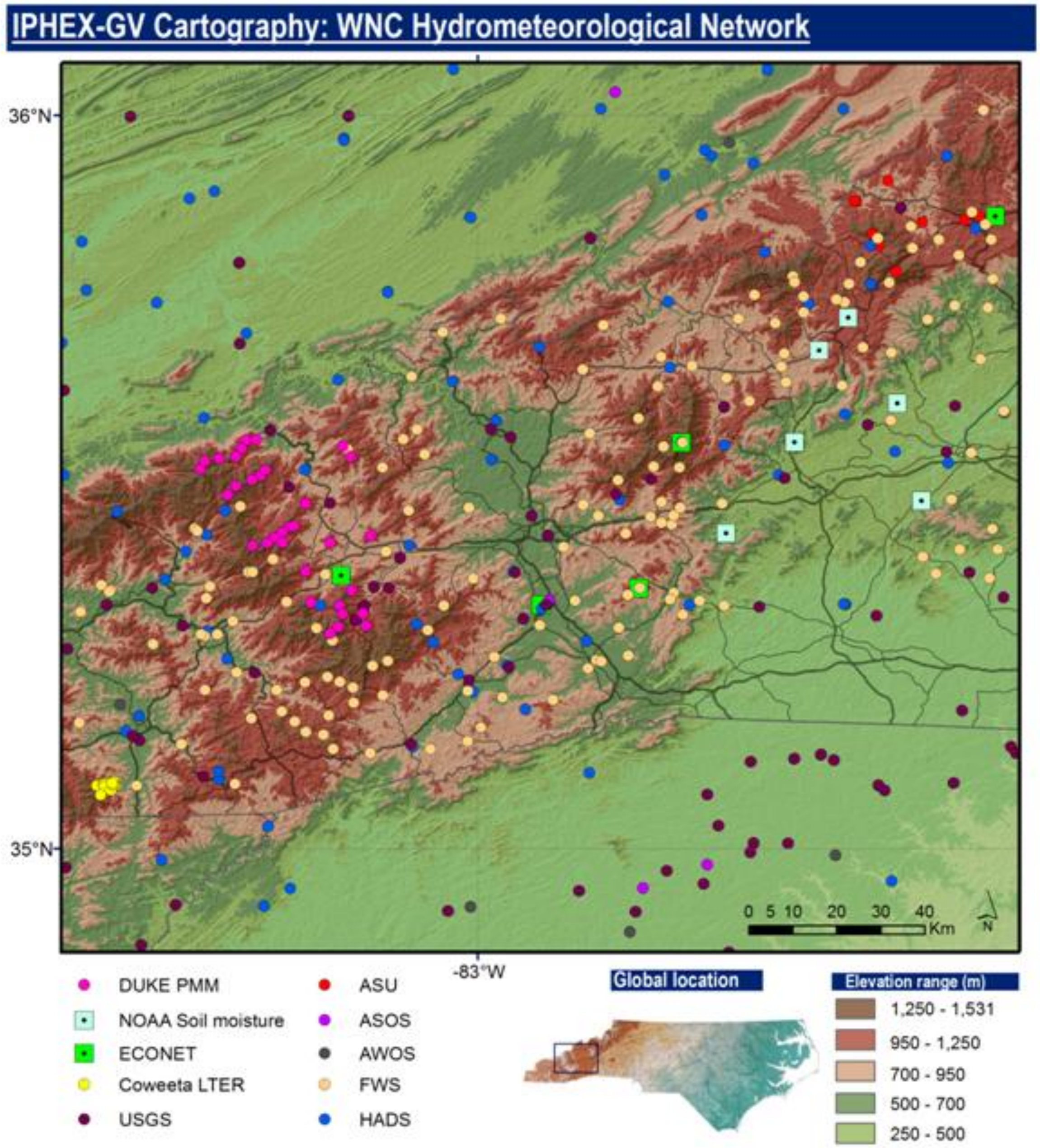


Figure 2 - Long-term monitoring networks (≥ 5 years) in Western North Carolina: IPHEx Core area.

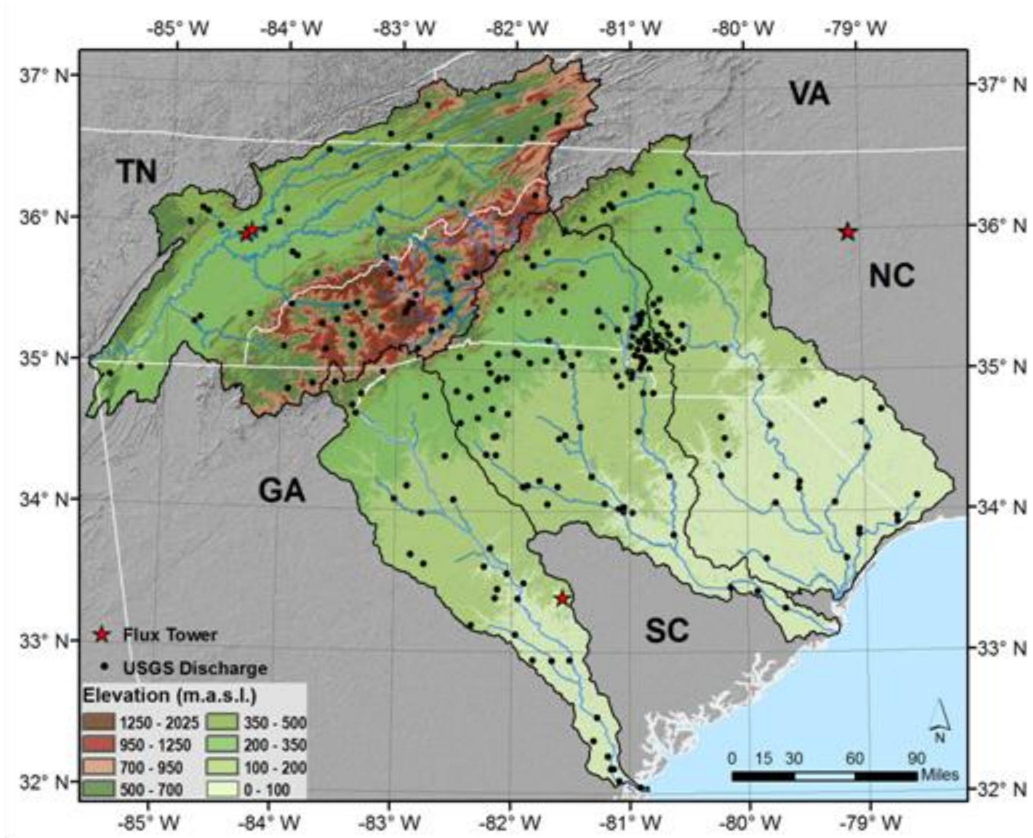


Figure 3 - Long-term monitoring networks (≥ 5 years) in Western North Carolina: USGS streamgauges over the extended IPHEx region.

1.2 Science Context

IPHEx aims to address questions regarding the 3D structure and life cycle of orographic and convective precipitation in continental regions of complex and heterogeneous terrain and moderate orography (elevations < 2,500m), which are characteristic of the eastern United States as well middle mountains and the rainy foothills of the world's dominant orographic barriers in the tropics and at mid-latitudes, where TRMM precipitation products show large biases for both heavy and light precipitation events (Barros et al. 2000, Prat and Barros 2010a; Duan and Barros, 2014). Previous work using MicroRain Radars (MRRs) in the inner region of the Southern Appalachians indicates that there is strong seasonal DSD dependency on rainfall type and location in the landscape (elevation, landform: ridge-valley locations), inner region versus upwind or downwind slopes (Prat and Barros 2010b; Wilson and Barros, 2014).

The headwaters of major SE river basins the Little Tennessee, the French Broad, the Catawba, and the Yadkin are located in the Southern Appalachians. In recent years the region is frequently in state of severe drought along with frequent flashfloods, especially in urban areas and at high elevations, where other natural hazards are frequent such as debris flows and landslides (Tao and Barros 2014a and 2014b, Villarini and Smith, 2010; Shepherd et al. 2010). Historical data analysis of Piedmont rainfall (including urban areas) suggests positive precipitation trends, and increased rainfall intensity over the recent decades (Li et al. 2013, Kunkel et al. 2013). On the other hand, light rainfall, defined as hourly rainfall rates less than 3-5 mm/hr, explains up to 60 % of the annual rainfall amount in the Southern Appalachians (Wilson and Barros, 2014), which has implications for the regional water budget and extreme hydrologic regimes. IPHEx will enable detailed hydrologic process studies to understand drought leading to improved water resources management.

In the warm season, four major rainfall regimes dominate in this region: (1) Light to moderate rainfall (Rainrate < 5 mm/hr) associated with orographic modulation of incoming moist air masses and seeder-feeder interactions (> 50% of all observed rainfall rates fall in this category); (2) Heavy short duration rainfall and graupel associated with isolated thunderstorms with initiation in the inner mountain region; (3) Heavy rainfall associated with westerly and southerly convective systems modulated by orography as they propagate across the inner ridge-valley region; and 4) Very heavy rainfall Tropical and Extratropical Systems (typically southerly and southeasterly). Over the Southern Appalachians, precipitation in regimes (1), (2) and (3) plays a key role in the regional water budget, whereas precipitation associated with regime (4) tends to be associated with various hydrological hazards as well as drought recovery (e.g. Fuhrman et al. 2008, Brun and Barros 2013). Although weaker than the Low Level Jet (LLJ) in the Central Plains (Anderson and Arritt, 2001), it is possible that the nocturnal LLJ east of the Appalachians play an important role on the diurnal cycle of rainfall on analysis of profile observations in the Mid-Atlantic states (Zhang et al. 2006). However, current evidence from the existing relatively sparse network of observations is lacking. Prat and Barros (2010b) reported an overall bias of TRMM PR 2A25 against measurements from a high-density raingauge network in the Smoky Mountains of up to 60% for heavy precipitation events in this region, whereas 80% of missed rainfall falls in the light rainfall category. Wilson and Barros (2014) propose that these missed light rainfall events as well as underestimation of rainfall in the case of stratiform systems and shallow convection can be attributed to seeder –feeder interactions among local fog banks and cap clouds and incoming weather systems. Mitrescu et al. (2010) report a preliminary CloudSat climatology for light and moderate rainfall events that is consistent with local observations, thus suggesting that, although for different sensors, there is great opportunity to improve light rainfall estimation over complex terrain with the GPM DPR Dual-frequency Precipitation Radar). Recently, an error analysis of TRMM PR 2A25 by Duan and Barros (2014) indicates that there is significant spatial and temporal organization of retrieval errors that is associated to topographic features and can be explained in relation to the predominant hydrometeorological regimes. In the inner mountain region of the Upper Tennessee, including the Pigeon and the French-Broad basin, hail-producing severe storms characterized by very strong winds in the valleys and heavy rainfall at higher elevations leading to floods and landslides tend to occur in the late afternoon and at night (see Appendix A).

There is strong evidence in the literature suggesting that organic aerosols, and especially giant aerosol of biogenic origin, play an important role on the time-scales of cloud development, and presumably fog, in forested ecosystems (Pöschl et al 2010, Pauliquevis et al. 2007). Given the recent interest on the influence of aerosols on orographic rainfall in regions of complex terrain (e.g. Rosenfeld et al. 2007), especially downwind of urban areas or pollution sources, and given the relatively low anthropogenic pollution in the region, IPHEx can also make an important contribution to clarifying the role of local vis-a- vis remote aerosol sources in the spatio-temporal persistence of fog regimes.

Atallah et al. (2007) described, using quasi-geostrophic and potential temperature frameworks, how tropical cyclones transitioning to extratropical systems evolve to be "left/right of track" precipitation dominant. Under either scenario, the IPHEx domain in our proposed region is often affected especially along the Piedmont and coastal regions by storms that track and landfall in the Atlantic SE region (Hart and Evans 2003), whereas the Southern Appalachians are strongly affected by Gulf storms as well as Atlantic storms (e.g. Brun and Barros 2013; Sun and Barros 2012; Konrad and Perry 2009). Left (right) of track scenarios may be associated with landfalling storms along the Carolina (Gulf) coast. Brennan and Lackmann (2005) have investigated the role of incipient precipitation and cyclogenesis in the region. They noted that the area of study (and other parts of the southeast) can be significantly affected by incipient precipitation (IP) prior to coastal cyclogenesis associated with lower-tropospheric diabatic PV maximum.

Shepherd et al. (2010) recently reviewed the knowledge base concerning the "urban rainfall effect". This is quite relevant as several major and growing urban areas (Atlanta, Charlotte, Greenville-Spartanburg, and Columbia) reside within our proposed area. Recent analysis of PRISM rainfall along the I-85 corridor reveals that some of the largest positive trends in precipitation are over are downwind of Atlanta, Charlotte, and Columbia as Shepherd et al. (2002) noted in their analysis of TRMM data. Several hypotheses (heat island destabilization, enhanced convergence, bifurcation, aerosol indirect effects) have been put forth, but none are conclusive at this point. Further, recent urban flooding in Atlanta, Nashville, and other cities heightens the need to understand urban hydrometeorological processes. In Charlotte, NC increased impervious surface extent within the Charlotte metro area has resulted in an increase in heavy runoff/urban flooding events, which can be particular severe for Tropical Storms (Wright 2013). Flood response in urban watersheds tends to be associated with return periods that exceed those in rural watersheds by as much as one order of magnitude (Brun and Barros 2013).

In addition to high biodiversity and complex topography and hydrogeology, the Southern Appalachians and the adjacent Piedmont areas exhibit a broad diversity of hydro-climatic and physiographic characteristics thus providing a representative domain for the evaluation of hydrologic modeling and forecasting skill including quantification and attribution of uncertainty conditional on precipitation estimates. In the COA (Fig.1), the annual cycle of precipitation is characterized by high precipitation (the highest in the eastern US) distributed rather uniformly throughout the year: cold-season hydrometeorology is representative of mid-latitude middle mountains; warm-season hydrometeorology is representative of tropical middle mountains. Second, persistent daytime haze and fog in the inner mountain region and their impacts on light and rainfall regimes resemble those found in tropical cloud forests, though at higher elevations, such as the eastern slopes of the Andes, and the cloud forests of the American Cordillera more generally. Finally, because of frequent landslide activity, widespread flash-flooding, frequent drought, wild fires, highly heterogeneous land-use and land-cover (LULC) ranging from fully forested protected areas in the Great Smokies National Park (Pigeon River basin) to intense agriculture in the Yadkin and Upper Catawba, and rapidly urbanizing areas along the I85 corridor from Atlanta to Raleigh passing through Charlotte, existence of large number of dams and reservoirs, the extended IPHEx domain provides ample opportunity to test hydrologic models and the propagation of precipitation uncertainty under a wide range of conditions.

2. Science Objectives

The GPM GV Science Implementation Plan (GVSIP) lays out three different strategies to evaluation, validation and improvement of GPM satellite constellation measurements, products, and algorithms:1) reliance on national networks and national infrastructure including operational observations (e.g. Figs. 2 and 3) and models ; 2) physical validation studies and comprehensive field campaigns targeting specific meteorological and hydrometeorological processes and regimes that bear directly on the assumptions used in physically-based retrieval algorithms and resultant precipitation products; and 3) integrated hydrometeorological applications that focus on utilizing satellite precipitation products for water cycle research and hydrologic operations including water resources management. In the context of each strategy, specific validation tasks consist of: core satellite error characterization; constellation satellite validation; assessment of radar and radiometer retrieval uncertainties; cloud resolving model validation; and coupled land-atmosphere and hydrologic model validation. IPHEx science objectives are aligned with core GPM research activities on physical validation and integrated hydrometeorological applications.

2.1 GPM Physical Validation - A 4D space-time data base of evolution of the microphysical properties of precipitation for various storm trajectories and precipitation regimes in the spring-summer transition over complex terrain (westerly mesoscale convective systems including severe weather systems such as derechos and super cells, frontal systems, shallow embedded convection, and orographic precipitation processes) will be collected. Observation of the widest variety of dominant precipitation modes over the complex terrain of the region is desired to extent that even a small number of oceanic cases are collected for contrast. Given the predominant use of higher frequency radiometer channels and associated ice-scattering signatures in GPM algorithms used to estimate rainfall over land surfaces, coincident air and ground based radar and airborne radiometer observations that support studies of the coupling between ice processes and the production of rainfall (i.e., that measured at the ground) will be critical. In the rain, vertical profiles of drop size distributions from the melting layer down to the ground surface as well as robust estimates of path-integrated-attenuation at high spatial resolution that can be used for the parameterization of microphysical processes will provide a critical benchmark for rapid evaluation and improvement of retrieval algorithms after launch. In addition, synergetic research in the region including high-density mesonets of soil moisture and surface temperature measurements should provide valuable estimates of surface emissivity and its diurnal cycle for the GMI and hence airborne clear-air land surface sampling missions will also be desired.

2.2 GPM Precipitation Science – The observations will permit detailed space-time mapping of the vertical structure of precipitation microstructure in the lower 2-3 km of the troposphere in complex terrain for conditions ranging from light to heavy rainfall. Besides its importance for retrieval, these data will be used to investigate the processes that govern orographic microphysical transients and how this affects spatial and temporal variability of rainfall intensity in complex terrain. This should lead to better understanding toward improving the representation of microphysical processes in models and therefore the prediction of the spatial and temporal variability of rainfall rates.

Because of the importance of persistent fog and low level orographic clouds on local enhancement of rainfall rates, understanding the role of local aerosols on the time-scales of cloud development and eventually precipitation initiation, duration and intensity is important. In addition, these local aerosols may play an important role in enabling the re-initiation of convective cells in the inner mountain region that are suppressed when westerly convective systems cross over the western slopes of the Appalachians. Summit-to-Piedmont transects of rainfall microphysics, rainfall microstructure and aerosol characteristics (biogenic, urban, marine sources) should allow unprecedented opportunity for detection and attribution studies of aerosol-cloud-rainfall interactions.

Radiosondes, profiler and radar data and modeling studies will provide for the first time a detailed characterization of the LLJ on the eastern slopes and investigate its role in regional precipitation, in particular the diurnal cycle on the eastern slopes of the Southern Appalachians and the Piedmont. Detailed 360^o radar mapping, profiling and soundings in the inner mountain region as well as western and eastern slopes should provide valuable 4D data for data-assimilation and interpretive studies to the dynamics of convection over complex terrain.

2.3 GPM Hydrology and Integrated Validation – The overarching science objectives for the GPM Hydro-GV program in the context of IPHEx are to understand the spatial and temporal variability of the water/energy cycle in mountainous regions and adjacent foreland basins including the contribution of light rainfall to regional freshwater resources, the sensitivity of hydrologic response to the space-time patterns of heavy precipitation across scales, and the linkages between physical hydrologic processes and hydrogeohazards (e.g. floods, landslides and debris flows). For this purpose, specific efforts will focus on developing and evaluating models and data assimilation frameworks to demonstrate and facilitate the use of GPM 4D QPE (Quantitative Precipitation Estimates) in global water and energy cycle research, weather prediction, and hydrologic applications. Special emphasis is placed on the characterization of uncertainties through the implementation of regional hydrometeorological testbeds across diverse hydroclimatic and physiographic regions including: characterization of uncertainties in satellite and ground-based precipitation estimates over a broad range of space and time scales; characterization of uncertainties in hydrologic models and understanding propagation of input uncertainties into model forecasts; assessing performance of satellite precipitation products in hydrologic applications over a range of space-time scales; and leverage data of synergistic NASA missions. The ultimate objective is to develop a foundation upon which the Hydro-GV program can measure progress in terms of new retrieval algorithms, new downscaling approaches, and advanced hydrological and other application models (Peters-Lidard and PMM Hydrology Working Group, 2011).

A core activity of IPHEx is the H4SE Hydro-GV testbed, a model intercomparison study aimed at benchmarking the performance of hydrologic models and model propagation of uncertainty in precipitation estimates to uncertainty of hydrologic predictions from the event to interannual time-scales, and over a wide range of watershed scales characterized by high heterogeneity of terrain, hydrogeology, land-use and land-cover and hydrometeorological regimes. Four large river basins with headwaters in the southern

Appalachians and which are geographically connected were selected: Upper Tennessee, Yadkin-PeeDee, Catawba-Santee and Savannah (Fig.1). These watersheds encompass a wide range of topographic and hydrogeologic settings (Fig.4) and modes of surface-groundwater interactions across four physiographic provinces: the Coastal Plain, the Piedmont, the Blue Ridge and the Valley and Ridge. Karst topography can be found in the Upper Tennessee river basin within the Valley and Ridge province and in the lower Savannah, Santee and Pee Dee river basins in Georgia and South Carolina. Land–Use and Land-Cover are very heterogeneous with predominance of natural forests, and agricultural and urban uses (Fig.5).

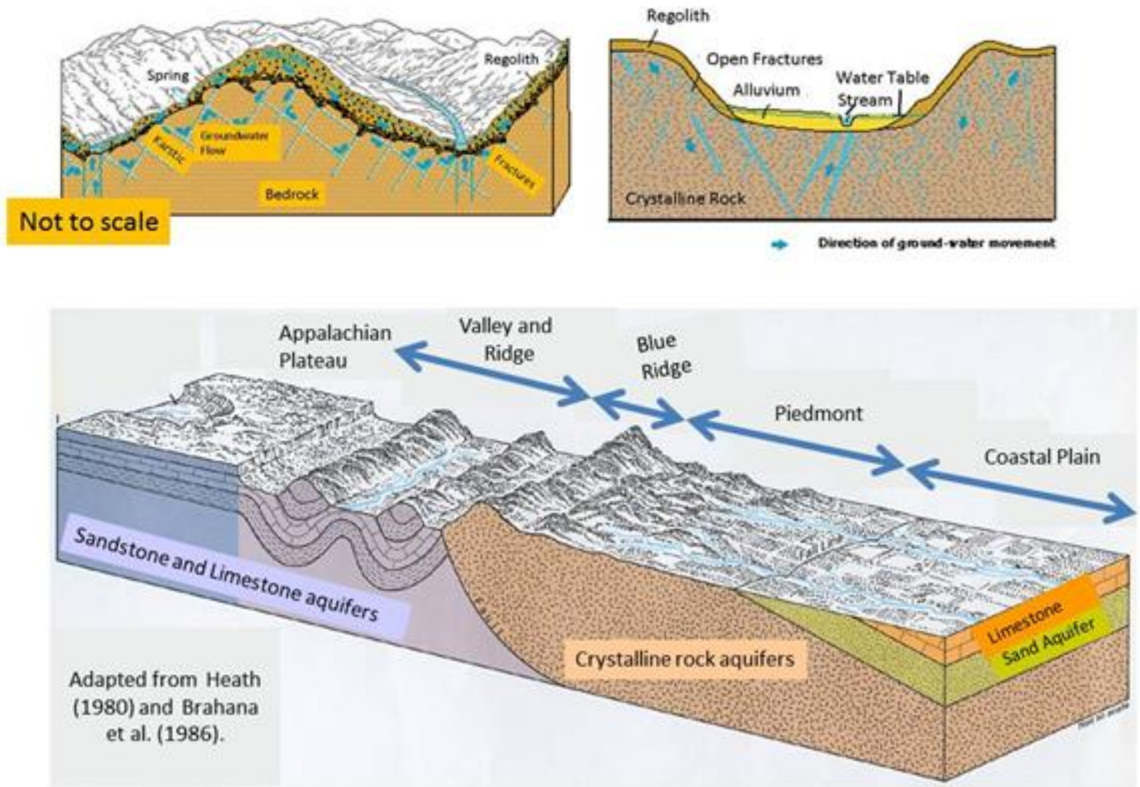


Figure 4 – Hydrogeology in the IPHEx domain (bottom panel) and modes of surface-groundwater interactions (top panels).

The H4SE activities consists of two phases: 1) a model implementation and evaluation phase during which participant hydrologic models will have access to a common data base of ancillary data and atmospheric forcing derived from NARR (North American Reanalysis) including observational QPE (Quantitative Precipitation Estimates) ; and 2) an operational testbed during the IPHEx IOP. Weather forecasts and QPF produced by Goddard's NU WRF modeling framework at high spatial resolution will be used as atmospheric forcing to run hydrologic forecast models every day. Daily hydrologic forecasts driven by NUWRF QPF will subsequently be compared against model forecasts for the same day using multisensory QPE. All participants will submit the forecasts to a common web site to be evaluated using the same metrics.

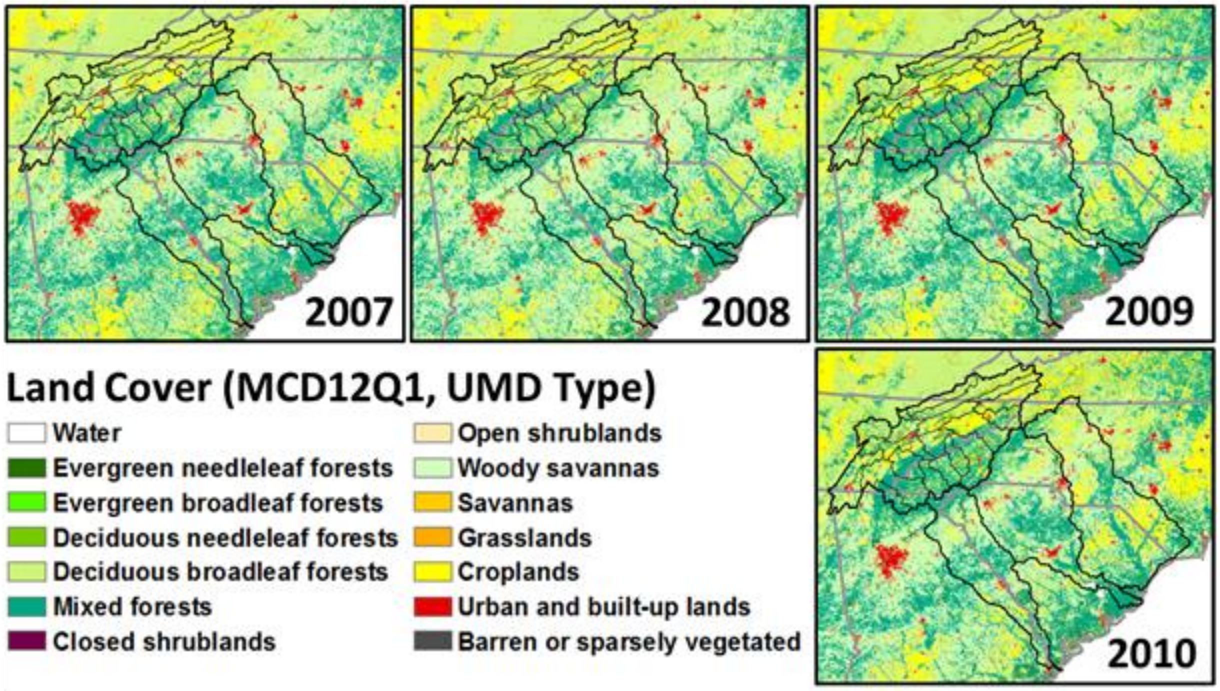


Figure 5 –MODIS yearly land cover product at 500m (MCD12Q1, Collection V51)-Type2/UMD) from 2007 to 2010.

2.4 Synergies with NOAA HMT-SEPS and Ongoing Activities

Hydrometeorology Testbed (HMT) researchers at NOAA Earth Science Research Laboratory (ESRL) also will be conducting data assimilation experiments with high-resolution forecast models that will assimilate the IPHEx datasets. The NOAA HMT is currently adopting the Community Hydrologic Prediction System (CHPS) to facilitate interoperability of hydrologic information with the NOAA Office of Hydrologic Development (OHD) and NWS forecast offices around the country, including the Southeast River Forecast Center (SERFC). CHPS provides a framework to allow HMT researchers to perform hydrologic simulations and exchange data with partner organizations across NOAA and the academic community. The goal is to better understand the sensitivity of hydrologic models, including the NOAA Research Distributed Hydrologic Model (RDHM) to various hydrologic forcing parameters (QPE, soil moisture, snow level, etc) as well as to examine the utility of providing ensemble stream flow forecasts using a WRF ensemble for input forcing. IPHEx will provide an opportunity to expand HMT hydrologic research to watersheds in the southeast and will highly complement similar efforts of NASA GPM investigators.

Other broad activities include: (1) Validation of global multi-satellite rainfall products of complex terrain precipitation: synergetic collaboration between IPHEx (limited duration intense observations) and HMT-SEPS observational programs can provide a large areal extent of high-quality surface rainfall fields derived from radar and rain gauge observations, associated with the various terrain areas (coastal, foothills and mountainous); and (2) Assessing the performance of satellite rainfall products in hydrological applications over a range of small to large size basin scales (~150-60,000 km^2). This activity requires synergistic measurements of a number of hydro-meteorological variables at watershed scale. The IPHEx domain includes one USGS Hydrologic benchmark watershed within the area of the PMM raingauge network in the Smokies, the NSF LTER at Coweeta, several USFS and NPS research stations, as well as several carefully monitored river basins including the Yadin and the Catawba near the core IPHEx area. The evaluation of satellite precipitation retrievals by NASA GPM investigators will complement similar efforts at NOAA. In particular, HMT researchers will use the precipitation measurements collected during IPHEx (gauge, radar, and satellite) to evaluate the performance of selected QPE algorithms, including Mountain Mapper (Schaake et al. 2004), Multi-sensor Precipitation Estimator (MPE; National Weather Service 2010) and NMQ Q2 (Zhang and Qi, 2010). This effort includes a quantitative assessment of the added value of satellite data for QPE and is part of a larger HMT goal to determine the “best possible” QPE in regions of complex terrain, resulting in improved hydrologic forcing guidance for NOAA’s National Water Center (NWC).

3. Science Questions

The following science questions will be investigated:

- How do precipitation ice processes couple to dominant rainfall production modes and how robust is the ice-rainfall signature in high-frequency (e.g., $\geq$ 89 GHz) microwave radiometer observations?

- What are the characteristic profiles and variability of the DSD and how do microphysical mechanisms explain the observed spatial and temporal variability of DSDs as a function of precipitation regime?

- How do dense fog and feeder-seeder mechanisms affect the vertical structure of airborne reflectivity profiles vis-à-vis surface radar?
- Is there a topo-morphology of satellite based precipitation errors consistent with convective and orographic precipitation habits in complex terrain?
- What are the error characteristics of the GPM-DPR and how do they compare against TRMM-PR rainfall estimates?
- What is the relationship between GPM-DPR and GPM-GMI error and local and regional hydrometeorological processes and regimes?
- What are the error characteristics of GPM-GMI in the context of local and regional land-surface and hydrometrological regimes?
- How does landform and land cover modulate propagating storms including suppression of existing and initiation of new convective cells?
- What is the spatial and temporal variability of warm season orographic precipitation and how does it depend on regional versus local scale dynamics and thermodynamics?
- What is the influence of aerosol physiochemical properties on fog and cloud development, and precipitation initiation? Is there significant variability in aerosol physiochemical properties due to intrusion of anthropogenic pollution in the Southern Appalachians?
- What is the impact of Piedmont urban areas on the morphology and intensity of storms?
- What are the relative contributions of light and heavy rainfall in their Appalachian headwaters to the freshwater resource accounting in the Yadkin and Catawba river basins? What is the relative dispersion of errors in satellite precipitation estimates of heavy and light rainfall among hydrologic states and processes in physically based models?
- How do errors from satellite precipitation estimates (e.g. GPM) associated with light and heavy rainfall propagate to the basin-scale water budget at critical delivery points (e.g. Charlotte)?
- What is the role of surface-groundwater interactions in modulating (amplifying or decreasing) QPE uncertainty in hydrologic forecasts?

- How do errors from satellite precipitation estimates (e.g. TRMM) associated with very heavy rainfall events travel from lower to higher order tributaries as the flood peak propagates?
- What are the immediate (at –launch) gains in QPE capacity from incorporating GPM observations into operational forecasts?

Data collected during IPHEx should nurture a wide range of research activities in support of PMM and GPM ground validation, science and applications as well as fundamental studies including: Physical and Dynamical Processes, Microphysical Processes, Aerosol-Cloud-Rainfall Interactions, Land-Atmosphere Interactions, Physical Hydrology, QPE and Water Resources Management.

4. Observational Plan

The observational plan consists of two stages: an Extended Observing Period (EOP) and an Intense Observing Period (IOP). The EOP began in the Fall of 2013 and will continue through the Fall of 2014. The IOP will take place May 1st through June 15, 2014. The final composition of the observational suite will be conditional on instrument availability and operational readiness, and costs to balance algorithm and science requirements.

4.1 Ground Observations

In addition to the instrumentation shown in Figs. 2 and 3, Fig. 6 below shows the current (present date) distribution of additional disdrometers and major radar and radiometer facilities to be operational during the Intense Observing Period. The large radars (NPOL, D3R and XPOL) will retire after the IOP, but the remainder ground observations will continue their deployment through the EOP (Table 1). Although most observations will be conducted eastward of the Appalachian divide, it is important that boundary conditions be obtained on the western slopes of the Appalachians in order to assure that detailed process modeling studies can be conducted for westerly systems.

The proposed core region is the yellow rectangle in Fig.1 which encompasses the French-Broad and the Catawba and Yadkin basins in North Carolina. Specific focus and a concentration of instrumentation are placed on/in the Pigeon Watershed of the French-Broad basin, which is in the Upper Tennessee. Two possible transects (defined loosely) for summit-to-sea studies across the extended regional area should also be feasible: Knoxville-Ashville-Charlotte-Wilmington and Knoxville-Ashville-Raleigh-Morehead City, and a third transect along the Atlanta-Charlotte-Raleigh urban corridor is also envisioned. These transects would further enable urban, coastal, and Piedmont-to-coastal transition hydrometeorology and hydrology studies.

Table 1 – IPHEx COA EOP Observational Ground Assets. COA- Core Observing Area; EOP- Extended Observing Period.

Sensors		**Inventory**
Raingauges	Duke/PMM	44
	NASA GPM GV	38
	National and State Networks (NWS, EPA, NPS, USDA, NC-FWS and Econet)	443
	HMT-SEPS	
	----	---- WXT
Disdrometers	Duke	17 P1 (16 UCLM) 4 P2
	NASA GPM GV	11 P2, 3 JWD, 5 2DVD
Radars	NEXRAD*	6
Profilers	HMT-SEPS	4
Streamgauges	USGS	129
	NSF LTER Weirs	22
	Private	
Soil Moisture	ECONET	
	SCAN	
	University	
Flux Towers	Duke	1
	Ameriflux	6
	NC- Other	
Wells	NC-DENR	
	USGS	
	NPS	
Meteorological Stations	NOAA	
	NC-Econet	
Radiosondes	NOAA NWS	KSNA, KFFC, KGSO, KRNK, KMHX
	UNC-Ashville	1 (mobile)
MRRS	Duke	2
	NASA	4
FOG	Duke	PCASP, MWR (3), CCN

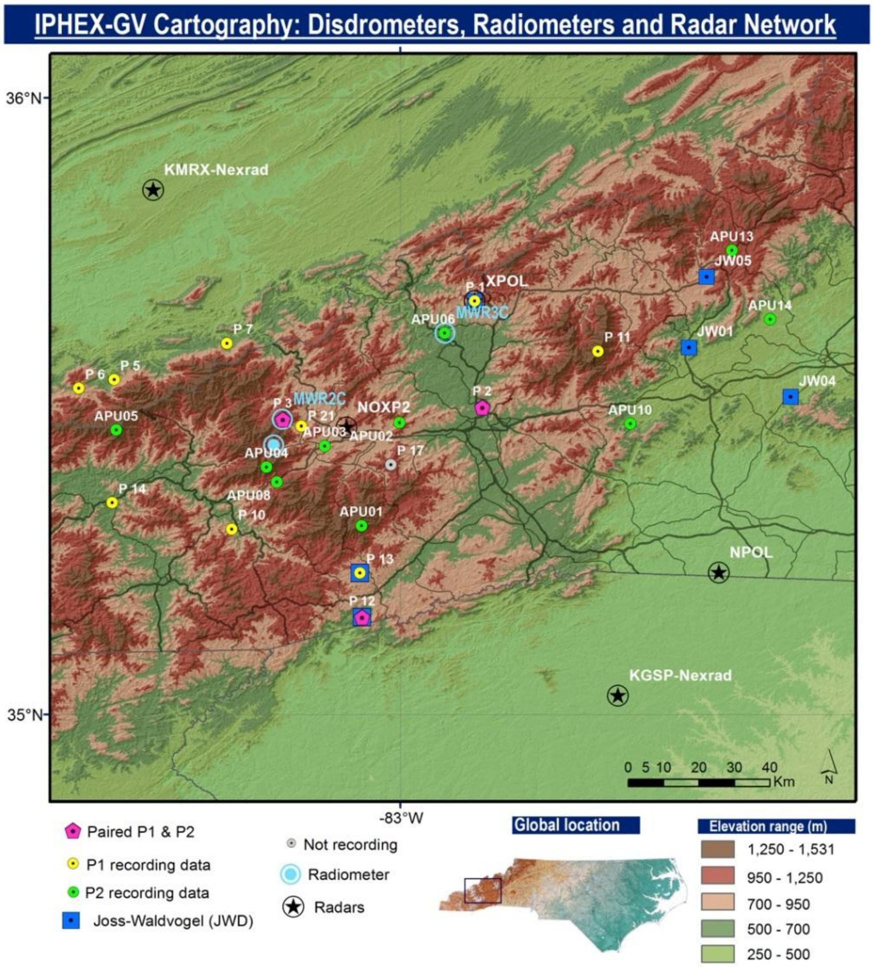


Figure 6 – Current network of fixed instrumentation during the IPHEx IOP. *[This map will continue to be updated with instruments]*.

4.1.1 NASA NPOL and D3R Radars

NASA's S-band dual-POLarimetric (NPOL) radar (Table 2, Fig. 7) and Dual-Frequency Ka-Ku band Dual-Polarimetric Doppler Radar (D3R) will be located roughly 30 km north of Spartanburg, South Carolina at 35.196203N, -81.963758W.

Briefly, the NPOL radar is a 0.93° scanning dual-polarimetric S-band radar. It operates in PPI sector or full volume mode, RHI mode, and vertically pointing mode. Polarimetric moments can be collected in either simultaneous transmit and receive (STAR) mode, or in an alternating H/V mode using a fast mechanical switch. The most common operations mode for NPOL is STAR in order to facilitate more rapid scanning. The radar is operated using Vaisala IRIS radar software and data are processed with an RVP900 signal processor.

Figure 7 - NPOL and D3R Radars as deployed in Iowa during the IFloodS campaign.

Table 2 - NASA S-Band Dual Polarimetric Radar (NPOL) Characteristics

Transmitter	
Transmitter Type	Coaxial Magnetron
Modulator Type	Solid State
Operating Frequency	2700-2900 MHz tunable
Polarization	Horizontal, Vertical, Simultaneous, Alternating
Peak Pulse Power Output (STAR)	425 KW H, 425 KW V typical
Peak Pulse Power Output(H, V an	850 KW typical
Pulse Width	0.8 or 2.0 s, selectable
PRF	250 to 1200 Hz
Antenna	
Reflector Type	8.5 m Prime-Focus Parabolic
Beamwidth	0.93 at +3 dB H, 0.94 at +3 dB V
Pedestal Type	Elevation over Azimuth
Types of scan patterns	PPI, RHI, Full Volume, Sector
Azimuth Angular Velocity	1 deg/s to 20 deg/s
Azimuth Angular Acceleration	20 deg s-2
Azimuth Position Accuracy	0.1 degree
Receiver	
Dual Receiver	Independent receivers for H/V signals
Operating Frequencies	2700 MHz to 2900 MHz
Digital Receiver	Vaisala RVP900 / IFDR
Data	
Moments	PPI Full, PPI Sector, Manual, RHI and
	Executable (Shell Commands)
	Pulse Pair Processing
	T (Total Reflectivity)
	Z (Reflectivity)
	V (Doppler Mean Velocity)
	W (Doppler Spectrum Width)
	SQI (Signal Quality Index)
	ZDR (Differential Reflectivity)
	KDP (Specific Differential Phase)
	PhiDP (Differential Phase)
	RhoHV (Cross Channel Correlation Coefficient)
	LDR (Depolarization Ratio)
	I & Q (Time Series)

Table 2 above provides a description of the radar transmitter, antenna, receiver as well as a summary of the science data that can be collected.

A near-real-time data system will also be employed to provide updated imagery of several fields of interest: reflectivity, differential reflectivity, rain rate, specific differential phase, co-polar correlation and hydrometeor identification. Additionally, two drop size distribution (DSD) fields will be retrieved: N_w (normalized intercept) and D_0 (median drop diameter). The radar will send these images to a NASA server for public display via the following web site: http://wallops-prf.gsfc.nasa.gov/Field_Campaigns/IPHEx/. If communication bandwidth allows, the raw data will also be sent over the internet. If not, then data will copied on site and then hand carried to NASA for further processing.

It is anticipated that NPOL will be ready for data collection at least one week prior to the IPHEx campaign in order to assess terrain blockage. Once this is done, a set of near-real-time blockage and hybrid scan algorithms will be implemented prior to processing of the data. The NPOL radar will generally be operated on a 24/7 basis.

The NASA Ka-Ku band Deployable Dual-Polarimetric Doppler Scanning Radar (D3R; Figure 7; Table 2) will be co-deployed with the NPOL during IPHEx, as it was during Iowa Flood Studies campaign in 2013. D3R provides a ground-based means to a) bridge observations of cloud and precipitation water in liquid and solid forms using frequencies consistent with the DPR; and b) provide a frequency-consistent test platform for development and testing of DPR retrieval algorithms. The D3R will be used for scanning in coordination with the adjacent NPOL radar (a relatively unattenuated wavelength) to test GPM dual-frequency path integrated attenuation (PIA), rain rate, DSD, and hydrometeor identification (e.g. liquid, melting, solid) retrievals. Engineering specifications for the D3R are provided in Table 3.

The principal scientific use of NPOL in IPHEx will be targeted toward providing high-quality, relatively unattenuated, polarimetric rain mapping and observations of microphysical processes occurring in the vertical column. It is acknowledged, however, that blockage corrections will be necessary in this region and polarimetry will be useful for this purpose. Use of NPOL in this fashion will satisfy GPM integrated hydrologic and physical validation scientific objectives that place a premium on quality regional rainfall products for benchmarking satellite retrievals and hydrologic models, diagnosing distributions of particle size, shape, and phase in the vertical. and providing an unattenuated reflectivity reference for studies of path integrated attenuation at Ka/Ku frequencies (e.g., those available from the GPM DPR and/or the D3R).

Table 3 - D3R Engineering characteristics

System	
Frequency	Ku- 13.91GHz ± 25MHz; Ka- 35.56GHz ± 25MHz
Minimum detectable signal (Ku, Ka)	-8 dBZ, -2 dBZ noise equivalent at 15 km, at 150m range resolution
Minimum operational range	450 m
Operational range resolution	150 m (nominal)
Maximum range	30 km
Angular coverage	0-360° Az, -0.5-90° El (full hemisphere)
Antenna	
Parabolic reflector –Diameter	6 ft (72 in.) (Ku), 28 in. (Ka)
Gain	45.6 dBi (Ku), 44.3 dBi (Ka)
HPBW	0.89° (Ku), 0.90 (Ka)
Polarization (Ku, Ka)	Dual linear simult. and alternate (H and V)
Maximum side-lobe level (Ku, Ka)	~ -25 dB
Cross-polarization isolation (on axis)	< -30 dB
Ka-Ku beam alignment	Within 0.1 degrees
Scan capability	0-24°/s Az, 0-12°/s El
Scan types	PPI sector, RHI, Surveillance, Vertical pointing
Transmitter / Receiver	
Transmitter Architecture	Solid State Power Amplifier Modules
Peak Power / Duty cycle	200 W (Ku), 40 W (Ka) per H and V channel, Max duty cycle 30%
Receiver Noise figure	4.8 (Ku), 6.3 (Ka)
Receiver dynamic range (Ku, Ka)	~ 90 dB
Clutter Suppression	GMAP
Data Products	
Standard products	- Equivalent reflectivity factor (Z_h) (Ku, Ka) - Doppler velocity (unambiguous: 26 m/s)
Dual-polarization products	- Differential reflectivity (Z_{dr}) (Ku, Ka) - Differential propagation phase (φ_{dp}) (Ku, Ka) - Copolar correlation coefficient (ρ_{hv}) (Ku, Ka) - Linear depolarization ratio (LDR_h, LDR_v) (Ku, Ka) *(in alternate mode of operation)*
Data format	NETCDF

Both NPOL and D3R will perform full/sector volume Plan Position Indicator (PPI) and range height indicator (RHI) scans in. Primary emphases for NPOL/D3R scanning will be placed on: a) high quality hybrid rain-mapping scans (composites made from 1–3 elevation angles) performed at low levels, interspersed with b) rapid, high resolution sector PPI volume or RHI sampling of the vertical structure of precipitation as needed and coordinated with aircraft operations and/or satellite overpasses in the sampling domain. Scanning strategies (Fig. 8) employed by the NPOL and D3R will facilitate joint studies of the vertical structure of precipitation processes, rain and DSD variability, path integrated attenuation impacts and mitigation of GPM dual-frequency radar retrieval algorithms, and the coincident mapping of associated storm kinematics. Vertically pointing scans will be conducted on a targeted basis in light stratiform precipitation to facilitate calibration of differential reflectivity (ZDR). Other modifications to scanning will be considered on an as-needed basis.

Sweep Number	Elevation degrees	Elevation Step degrees	Elapsed Time seconds	Max Height Km	Range Intercept Km
1	1.00	0.573	28.5	2.3	100.0
2	1.57	0.573	39.5	3.3	100.0
3	2.15	0.573	50.5	4.3	100.1
4	2.72	0.572	61.5	5.3	100.1
5	3.29	0.572	72.5	6.3	100.2
6	3.86	0.572	83.5	7.3	100.2
7	4.43	0.571	94.5	8.3	100.3
8	5.01	0.571	105.5	9.3	100.4
9	5.58	0.570	116.5	10.3	100.5
10	6.15	0.570	127.5	11.3	100.6
11	6.72	0.558	138.5	12.3	102.6
12	7.27	0.605	149.5	13.3	94.8
13	7.88	0.654	160.5	14.3	87.5
14	8.53	0.708	171.5	15.4	80.9

Sweep Number	Elevation degrees	Elevation Step degrees	Elapsed Time seconds	Max Height Km	Range Intercept Km
1	1.00	1.432	25.5	0.8	40.0
2	2.43	1.431	33.5	1.8	40.0
3	3.86	1.429	41.5	2.8	40.1
4	5.29	1.426	49.5	3.8	40.2
5	6.72	1.422	57.5	4.8	40.3
6	8.14	1.418	65.5	5.8	40.4
7	9.56	1.412	73.5	6.7	40.6
8	10.97	1.406	81.5	7.7	40.7
9	12.38	1.399	89.5	8.7	41.0
10	13.77	1.391	97.5	9.6	41.2
11	15.17	1.382	105.5	10.6	41.4
12	16.55	1.373	113.5	11.5	41.7
13	17.92	1.469	121.5	12.4	39.0
14	19.39	1.585	129.5	13.4	36.1
15	20.97	1.709	137.5	14.4	33.5
16	22.68	1.841	145.5	15.5	31.1
17	24.52	1.981	153.5	16.7	28.9
18	26.50	2.130	161.5	17.9	26.9
19	28.63	2.287	169.5	19.3	25.0
20	30.92	2.452	177.5	20.6	23.4

Figure 8.- Left, 90 Degree "Far" sector scan. Right. 90 Degree "Near" sector scan.

4.1.2 NOAA X-band Polarimetric Radar (NOXP)

The NOXP radar (Palmer et al., 2009; also Table 4, Fig. 9) will be located on a low ridge within the Pigeon River basin (Fig. 6). This location will allow scanning of nearly the entire basin and thus capture most weather systems as reviewed in Section 2.

Figure 9 - NOAA NOXP mobile X-band dual-polarimetric radar.

In previous campaigns the NOXP has been used to study tornadogenesis during the Verification of the Origins of Rotation in Tornadoes Experiment – II (VORTEX-II) in 2009. It was also deployed to desert regions in Arizona during the summers of 2012-2013 to study thunderstorms, microbursts, and dust storms. NOXP was shipped to France for the Hydrological cycle in the Mediterranean Experiment during the autumn of 2012 (HyMeX; Ducroq et al., 2014).

Table 4 - NOXP Radar characteristics

Characteristics of the location	
Location	**Pigeon Watershed**
Coordinates Longitude : (WGS84) Latitude :	**Final TBD**
Altitude of the ground from sea level (m)	**Final TBD**
Antenna height above the ground (m)	**~4 m**
Minimum/Maximum elevation angle (°)	**0 / 90**
Characteristics of the transmitter/receiver	
Frequency (MHz) :	**9410**
Peak power at antenna port (dBW)	**47**
Equivalent Isotropically Radiated Power (EIRP) (dBW)	**47**
Wavelength	**3.22 cm**
Modulation type:	**Pulse**
Characteristics of the antenna	
Antenna type	**Parabolic Dish**
Antenna Gain (dBi)	**45.5**
-3dB antenna aperture (°)	**0.9**
Relative gain at horizon (dBi)	**45.5**
Polarization	**Dual Linear (STAR and H-mode only)**
Rotation speed (rpm) (min and max)	**0 - 5**

Scan capabilities	5 rpm (30 deg/s) in azimuth; 0-90° elevation; RHI capable
Range	Max range defined by selectable PRF; previous deployment used 1350 pulses/s which equates to 111 km
Communication capabilities	Voice: VHF radio, cell phone; data: USA cell-based wireless; 918 MHz radio

During IPHEx the NOXP will function to provide event-based watershed-scale volume scans of precipitation in the ridge/valley system of the Pigeon over the dense networks of surface instrumentation. During aircraft operations over the Pigeon area, the NOXP will collect sector volume and RHI scans in addition to its rain mapping VCP.

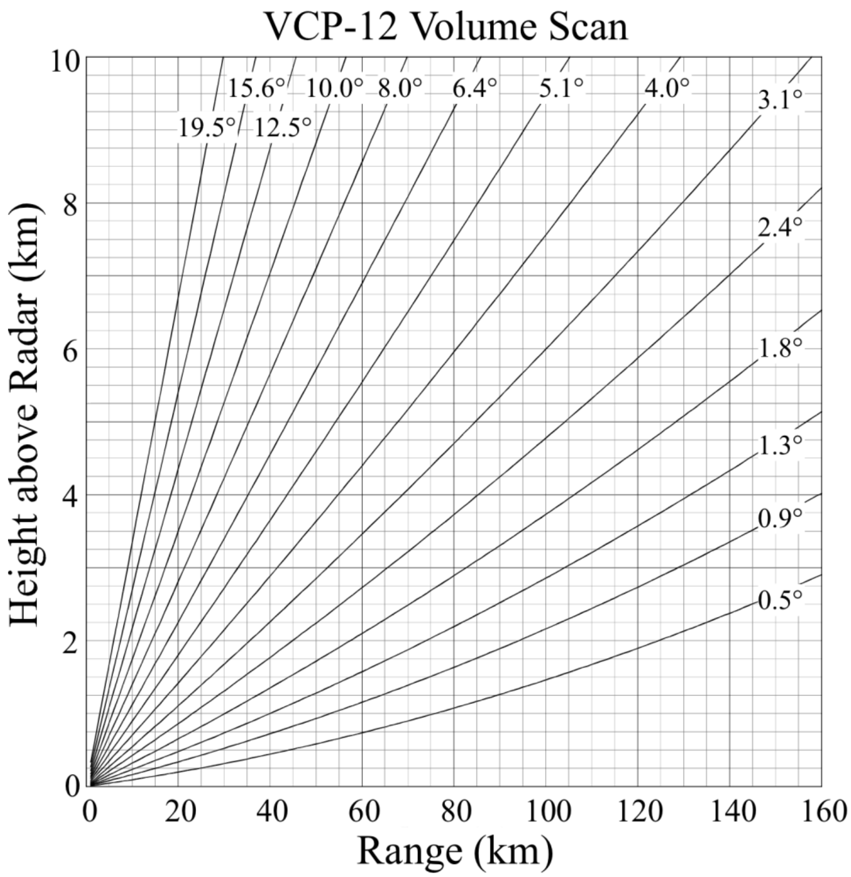


Figure 10. NOXP VCP-12 scan. Note that one angle at 0.1° has been added to the lower level tilts.

To facilitate ease of operation, enable constant sampling of low level rain/liquid character over the Pigeon Watershed, creation of hybrid-scan rain maps, and to support occasional aircraft operations, the NOXP radar will operate a near fixed full-volume scan. This scan, the VCP-12, is reflected in Fig. 10. Note that Fig. 10 does not include a 0.1° tilt added to account for the radar's increased elevation due to its location on a ridge. Also note that occasional RHI scans are not precluded from use with the VCP-12 and can be included at Radar Scientist or Mission Scientist request. Note that severe blockage of the NOXP beams occurs in a clockwise direction from roughly 330° to 100° at its planned ridge location.

4.1.3 Disdrometers and Rain Gauges

During IPHEx disdrometers and rain gauges (Figs 2 and 6) will provide a measure of the precipitation size distribution and accompanying precipitation rate at the surface. A network of collocated rain gauges will provide a rain rate reference comparison source for the disdrometer observations. Collectively, these observations offer an important constraint on the retrieval of both precipitation and near surface path integrated attenuation properties from ground-based radar. Specifically, when the disdrometer/gauge network data are combined with profiling radar data the goal is to provide a unified reference from which to extend DSD retrievals made using polarimetric radar algorithms to the broader 3D sampling domain. Accordingly, NASA GPM and Duke U. will deploy more than 40 disdrometers, 20 with raingauge pairs, consisting of five new 3rd-generation compact 2D Video Disdrometers (2DVD) and 30 or more Parsivel Disdrometers as shown in Fig. 6. Moreover two NASA Parsivel and three Joss Waldvogel disdrometers were also deployed at NOAA surface weather and profiler sites in the Catawba Basin.

Figure 11 - Pictures of the Automated Parsivel Unit (APU; left), 2DVD (middle) and dual-tipping bucket gauge system (right).

The 2DVDs (Fig. 11) will be oriented in an approximate ray northwestward of the NPOL/D3R radar pair, terminating at Purchase Knob in the Pigeon Watershed. The 2DVD network will provide anchor points for assuring overall calibration of the NPOL, D3R and NOXP radars, and a source for verifying blockage corrections to the lower tilts of NPOL scans. The 2DVDs will provide measurements of particle size and concentration for particles of 0.5 – >8 mm in diameter (bin resolution of 0.25 mm), axis ratio distribution, and fall-velocity information. The Parsivel network will provide spatially-distributed measures of rain DSD, particle phase, and fall-velocity. Particle sizes detected range from 0.3 mm to 20 cm, with a geometrically increasing bin size from 0.125 mm at 0.3 mm to 1 mm at 6 mm drop diameters.

Derived products from these instruments include rain rate, reflectivity, liquid water content, drop count and concentration, mass-weighted mean diameter D_m, max drop size, as well as the mass spectrum σ_m.

Approximately 20 NASA dual-rain gauge platforms have been added to the existing Duke network as well (Fig. 6). These platforms (Fig. 1) will provide 15-minute updates on rain intensity telemetered in real time from each site via sell modem. The augmented gauge network will provide calibrated rainfall rates at the gauge locations and a measure of the rainfall variability across the complex terrain.

4.1.4 Micro Rain Radars

Four NASA MRR2 radars (K-band; 24.25 GHz, CW) will be deployed in the observational domain around the Pigeon Watershed. MRR2s will provide a low level vertical profile of precipitation Doppler spectra that is integrated to provide profiles of radar reflectivity, precipitation rate, and DSD. The radars will be set to record data at 60 m gates to an altitude of approximately 1800 m AGL. Three MRRs will be deployed by Duke University at P1, P3 and APU06 in Fig. 6.

Three of the four MRR's will be located along the 2DVD ray extending outward form the NPOL/D3R site at Polk County Social Services, Green Creek Volunteer Fire Department, and Edneyville Elementary. The fourth MRR will be collocated with instruments on Mt. Pisgah, P17 in Fig. 6.

4.1.5 Radiosondes

During the IOP, radiosondes (iMet-3050 403 MHz GPS system, sold by International Met Systems) will be launched from the facilities belonging to the Atmospheric Science Department, UNC Ashville. The rawinsondes are capable of retrieving vertical profiles of air temperature, dewpoint temperature, elevation, pressure, and wind speed and direction (GPS-based wind estimates). For active weather conditions, radiosondes will be launched every 3-hours during daytime in the "day before" and in the "day of "the event. Launching frequency at night will reduced to two sondes to be complemented with AIRS observations, which have been determined to capture well nocturnal conditions against operational soundings (not shown) in the region. Such event related launches will be integrated with other profiler data (e.g. HMT-SEPS) for analysis and for data assimilation applications. In addition, approximately three clear-air soundings concurrent with GPM overpasses will be conducted in the mountains and between the mountains and the Piedmont in order to collect temperature and humidity profiles that will be used to estimate atmospheric correction for radiometer observations. Likewise, three radiosondes will also be launched from each location equipped with a Microwave Radiometer (Fig. 6) in order to obtain atmospheric structure information to evaluate the retrieval algorithm. A number of radiosondes (minimum of 12) will be reserved for the

EOP duration in anticipation of a tropical storm or a major storm system later in the summer season.

4.1.6 Aerosols, CCN, Fog and Clouds

These observations will the monitoring capabilities of Duke's H2F (Haze to Fog) mobile facility which includes: 1 MicroRain radar, 2 Disdrometers including a P2 disdrometer, 2 raingauges, 1 PCASP sensor for aerosols, wind, radiation and relative humidity sensors and will be colocated with a Microwave radiometer (integrated liquid water water) and one Pluvio weighing raingauge. In addition, we are expecting to deploy the ACHIEVE (see mobile laboratory alongside H2F to obtain the time-varying vertical structure of clouds and precipitation for IPHEX.

To effectively model the rainfall enhancement, the drip-fog extraction efficiency, and the aerosol deposition processes in the cloud forest, accurate ground-based measurements of the complete aerosol size distribution as well as concentrations of CCN active at fog-relevant supersaturation are required. The Petters' group at NC State University will piggy-back on the existing infrastructure of the IPHEX field campaign to collect the aerosol data during the IPHEX IOP and to provide a quality controlled archived data set for performing modeling studies of the feeder cloud formation and testing hypotheses of orographic rainfall enhancement. As part of the IOP, NCSU will provide and deploy the following instruments collocated with Duke's H2F (Haze to Fog) Mobile facility: a condensation particle counter (CPC, TSI 3771, total count D > 10nm); a scanning mobility particle sizing (SMPS, 10 nm < D < 500 nm) system consisting of an electrostatic classifier (TSI 3081L) and a condensation particle counter (TSI 3772); a single column cloud condensation nuclei (CCN) counter (Droplet Measurement Technologies, Model 100) operating at supersaturations simulating fog and low lying cloud formation (0.07 < s< 0.4%).%). A reduced archived level-2 dataset that contains (Petters and Kreidenweis, 2007, Christensen and Petters, 2012): a - Particle size number $\left(\frac{dN}{d\log D}\right)$, surface area $\left(\frac{dS}{d\log D}\right)$, and volume size distributions $\left(\frac{dV}{d\log D}\right)$. b- Multimodal lognormal size distribution parameters (N_t, D_{pg}, and σ_g). Aerosol hygroscopicity parameter (κ). c - Cumulative CCN supersaturation (s) spectra $\left(\frac{dN_{CCN}}{ds}\right)$. d- Fits of the cumulative CCN supersaturation spectra to the functional form suggested by Cohard et al. (1998) will be computed to initialize calculations of droplet number concentration.

4.1.7 ACHIEVE

ACHIEVE's Wband radar is a 94 GHz dual polarization pulsed scanning Doppler cloud radar with a beamwidth of 0. 25^o and a minimum detectable threshold of -55 dBZ at 1 km. The moment data products are radar reflectivity (dBZ), mean radial velocity (m s^{-1}), and velocity standard deviation (spectral width), as well as the Doppler power spectra.The radar can be configured to transmit and receive in either short pulse mode or pulse compression mode, with the latter permiting increased sensitivity and range resolution. The Wband range resolution typically varies from 12.5 to 50 m, maximum range varies from around 4 to 30 km, and data aqcuisition rates generally range from 0.25 to 4 s; all of these parameters are specified by the user. The radar is typically used in pulse compression mode to make measurements with 25 m range resolution and maximum range around 8.4 km. An experimental Xband (10.4 GHz; FM-CW) radar is also mounted on the pedestal beside the Wband radar. The Xband radar measures radar reflectivity associated with drizzle to moderate precipitation (~1 to 50 mm hr-^{1}) but is still under development. A vertically pointing commercial Kband Micro Rain Radar (MRR) (24 GHz; FM-CW) with a beamwidth of 1.5^o measures Doppler spectra and estimates vertical radar reflectivity profiles and Doppler velocities (~0.8 to 9 m s^{-1} with resolution of about 0.2 m s^{-1}). Range resolution of the MRR varies from 10 to 200 m, with a maximum range up to 6 km, and data acquisition rates range from 10 to 3600 s.

Other instruments include a ceilometer, an Atmospheric Emitted Radiance Interferometer (AERI), a sun photometer, rain gauges, and an all sky imager. A tyical setup of the mobile laboratory is shown in Fig.12. The Vaisala CL51 ceilometer uses a 910 nm wavelength laser to measure vertical profiles of attenuated backscatter and infer cloud base height for up to 3 cloud layers. The ceilometer has a range resolution of 10 m, a maximum range of 15 km (maximum cloud detection range is 13 km), and data are output every 6 to 120 s. The AERI measures absolute spectral radiances of downward thermal emissions over the spectral range of about 3 to 18 μm with 1 cm^{-1} spectral resolution. In cloud-free conditions, AERI can retrieve aerosol optical depth (AOD), coarse-mode particles such as sea-salt and mineral dust, especially near the source, particle size and composition, along with lower (up to ~ 4km) atmospheric profiles of temperature, pressure, and humidity. For cloudy conditions, AERI can retrieve cloud optical depth (COD) as well as T, p, and RH profiles below cloud. Data products from AERI are recorded at roughly 10 minute intervals. An upgraded AERONET/CIMEL sun photometer measures polarized radiances over an atmospheric column at 9 channels ranging from 340 to 1640 nm (8 aerosol channels and 1 water vapor channel) and operates in both cloud-free and cloud mode (when the instrument does not not detect a strong signal from the sun). Data are recorded approximately every 3 minutes and include AOD along with retrievals of aerosol size distributions and phase functions in cloud-free conditions, and retrieved COD from calibrated radiance values at channels 440 and 870 nm when operating in cloud mode. An optical rain gauge is mounted atop the trailer and measures both rain rate (specificied dynamic range of 0.1 up to 500 mm hr^{-1}) and total accumulation (specified up to 999 mm per 24 hour period), with variable data acquisition rates. A tipping bucket rain gauge (0.01 inches per tip, accuracy of ± 1% for 1 to 3 inches per hour rain rates and ± 3% for rain rates < 1 inch hr^{-1} or > 3 inch hr^{-1}) is also available. Lastly, an all-sky imager captures digital images of local hemispheric sky conditions every minute.

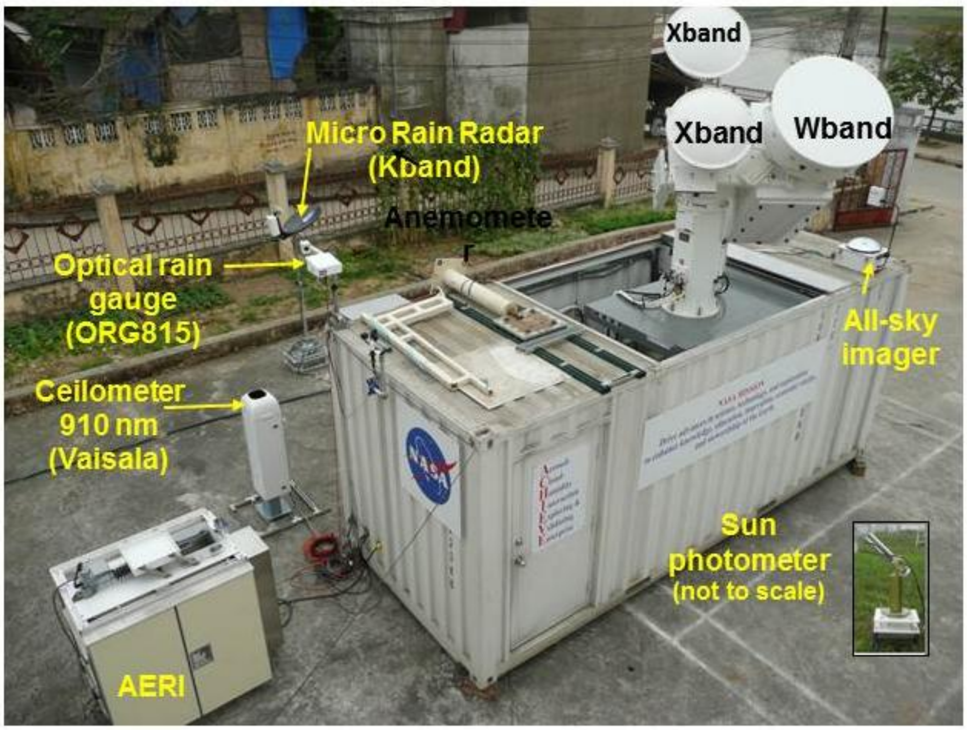


Figure 12 – Typical setup of the ACHIEVE mobile laboratory.

4.1.8 Groundwater Transit Times

An overarching question about role of groundwater in the mountainous study site (Pigeon River Watershed, or PRW) is, "what are the residence times of groundwater, as a function of geology, vegetation type, and scale?" Preliminary tracer data on groundwater age and transit time (from recharge at the water table to discharge at the stream) will be collected during IPHEx in the PRW. These data will be useful in evaluating preliminary numerical models of PRW hydrology used during IPHEx. Groundwater samples will be collected at eight locations for analysis of $SF6$ (an atmospherically-derived age dating tracer for groundwater ≤50 years old) and other dissolved gases. The eight samples will be collected beneath the streambed, in two 4-point transects across one of the major PRW streams (East or West Fork, Cataloochee Creek, or Jonathan Creek), with methods used successfully in previous work (Kennedy et al. 2009a). We will also measure groundwater seepage rate at the same eight streambed points (Genereux et al. 2008; Kennedy et al. 2009b). Dissolved silicon (Si) and other basic water quality parameters will be measured in these groundwater samples, and in other samples from beneath the streambed and/or from existing wells. Dissolved Si has been shown to have strong potential as an indicator for groundwater age, especially in crystalline hard-rock terrains such as the PRW. This data collection would give at least eight SF6 ages showing range of age in groundwater discharging to the study stream, and also, in combination with the streambed water flux data, providing a preliminary estimate of mean transit time through the groundwater system (as the flow-weighted mean of the groundwater ages; Kennedy et al. 2009a). These observations will provide the basis for future analysis of the distribution of groundwater ages in the PRW, and an indication of whether there are distinct groundwaters from two systems: young lower-solute, low-Alk water draining laterally from hillslope soils, and older, higher-solute, higher-Alk water draining from bedrock fracture networks, and thus transit times. These data can be used to evaluate the subsurface flow response to rainfall, which appears to be a critical factor in streamflow discharge and landslide initiation (Tao and Barros, 2014).

4.1.9 Soil Moisture

Soil moisture grab samples following the standard procedures outlined by the USDA will be collected (e.g. SMAPVEX1 experimental plan http://www.ars.usda.gov/) at permanent ECONET and, or NOAA sites that best fit with the flight path of the SLAP instrument (*Scanning L-band Active Passive*, see below) within the Catawba and the PRW basins, at the new soil moisture stations installed for IPHEx (pink and blue dots in Fig. 13) if feasible, and over the WISARD dense mini-networks in Duke Forest (Fig. 13).

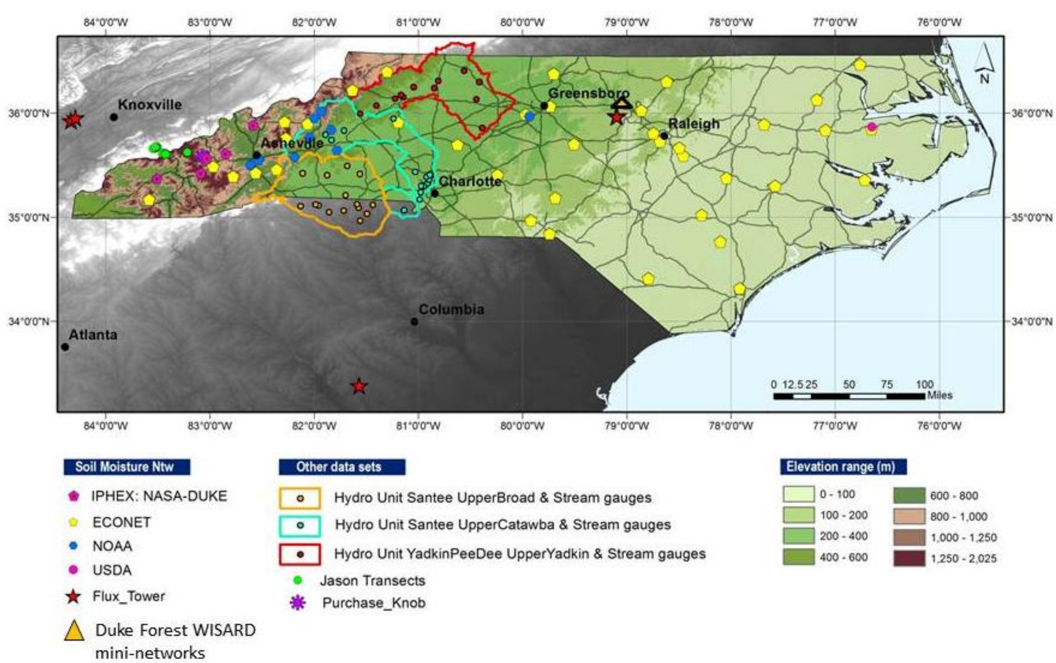
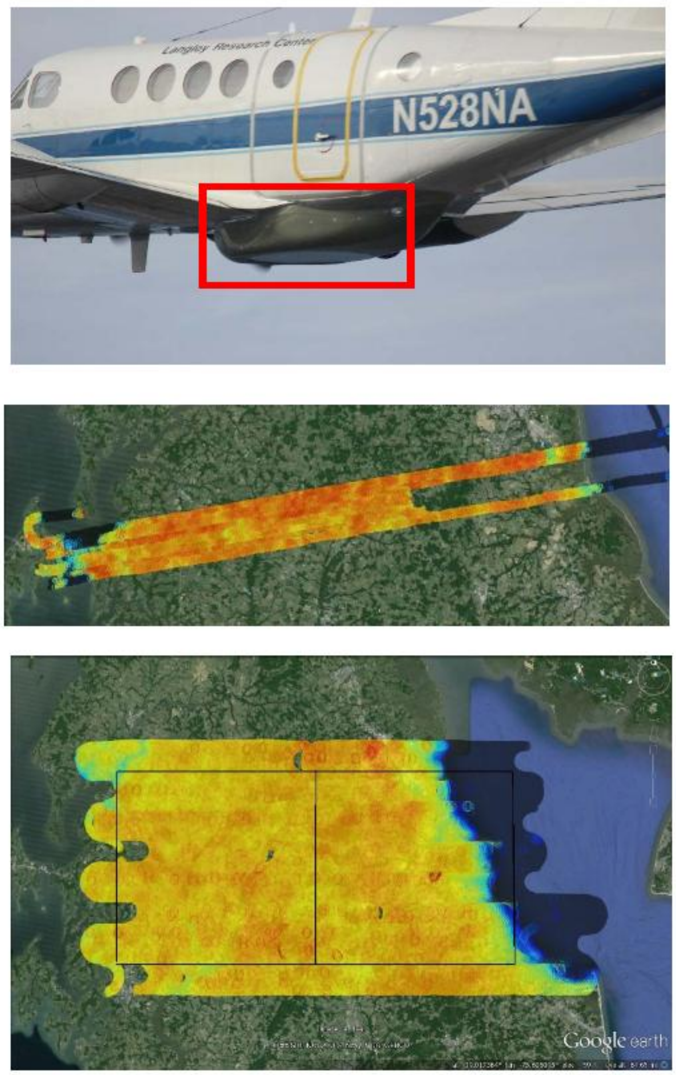


Figure 13 – Soil moisture stations in North Carolina during IPHEx.

Samples collected in the field in early morning will be preserved in hermetic bags, brought to the laboratory in the afternoon, weighed and dried to quantify soil water content. These data can be used in the future for research evaluating the soil moisture fields produced by aircraft, to initialize hydrologic models and to relate groundwater transit times to the spatial distribution of soil moisture as a function of hydrogeologic setting (Piedmont vs Blue Ridge).

Scanning L-band Active Passive (SLAP)



SLAP is an airborne simulator for SMAP, with both passive and active microwave imaging capability that matches SMAP's channels and scan geometry plus enhanced capabilities not found in SMAP. SLAP can observe soil moisture, soil freeze/thaw state, ocean salinity, sea ice, & ice sheets. Compatible with several new aircraft plus the usual P-3, C-130, & C-23; it is currently installed on NASA Langley's UC-12B King Air aircraft (Fig. 13, top panel). The radiometer is 4-pol (same as SMAP); the radar is quad-pol (SMAP is tri-pol). FAA granted permission to operate the radar during IPHEx. SLAP also includes a functional equivalent of SMAP Radio Frequency Interference (RFI) processor.

Figure 14 – SLAP aircraft installation and (top panel) and examples of high (200 m) and coarser (1 km) resolution observations for two different flying altitudes.

Example radiometer images (Fig. 14, middle & bottom panels) demonstrate typical capabilities: 2 flights in 1 day. The 1st flight (middle image) is a low altitude/high resolution—200m resolution/2000ft AGL flight. The second flight same day (bottom image) mid-altitude (11000 ft) mapping of two SMAP 36 X 36 km grid cells in <3 hrs with 1km resolution. The flights will take off from Langley and will fly over Lake Jordan before flying approaching the COA while measurements of surface lake water temperature in Jordan Lake will be collected for calibration of the radiometer. Subsequently, flights will be conducted in the Piedmont along the Appalachians footslope and adjacent plains from the Western to the Eastern Piedmont. Figures showing flight patterns and maps containing the final flight lines and ground validation sites are presented in Appendix B.

4.2 Aircraft Campaign

NASA will provide two aircraft for IPHEx: the NASA ER-2 and University of North Dakota (UND) Citation. These aircraft are being deployed to provide coordinated high-altitude radar and radiometer sampling of precipitation structure and in situ microphysics. The NASA ER-2 will function as a GPM instrument and core-satellite sampling simulator from high altitude during IPHEX. The aircraft can fly eight hour missions and will be operated out of Warner-Robbins AFB, Georgia at a nominal altitude of 20 km (65 kft) MSL. The data collection method for the ER-2 involves coordinated over-flights of an in situ microphysics aircraft (e.g., UND Citation) located at altitudes below ~10 km MSL. The UND Citation can fly four-hour duration missions (~3-hours on station) and will be located in Asheville, North Carolina, a very short ~ 40 km ferry to the central observation domain over the Pigeon Watershed and NPOL region. The combined ER-2 and UND microphysics data collection will enable validation of dual-frequency precipitation and path-integrated attenuation algorithms and combined radar-radiometer precipitation retrieval algorithm physics from the vantage point of a downward viewing platform, similar to that of the GPM Core satellite.

4.2.1 NASA ER-2 High-Altitude Aircraft

ER-2 instrumentation will include (Table 5, Fig. 15) a dual-frequency Ka-Ku band, dual-beam, nadir-pointing Doppler radar (the High Altitude Imaging wind and Rain Airborne Profiler, HIWRAP; Heymsfield et al., 2013), two multi-frequency passive microwave radiometers (the airborne Conical Scanning Millimeter-wave Imaging Radiometer, CoSMIR; and the Advanced Microwave Precipitation Radiometer, AMPR), a W-band cloud radar (ER-2 Cloud Radar System; CRS), and the dual-beam ER-2 X-band Doppler Radar (EXRAD). Not shown is the Lightning Imaging Package (LIP) to be flown on the ER-2 as a complementary "piggy-back" instrument for IPHEx, but designed and flown for GOES-R Geostationary Lightning Mapper validation.

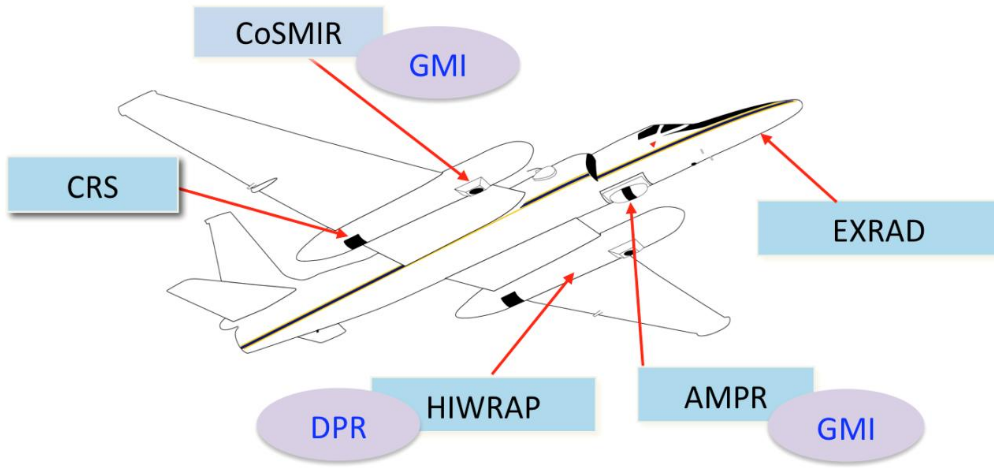


Figure 15. Location of IPHEx remote sensing instruments on the NASA ER-2 aircraft.

Table 5 - ER-2 Radiometer and Radar complement.

Instrument**	Characteristics
AMPR H+V (Radiometer)	10.7, 19.35, 37.1, 85.5 GHz (scanning)
Footprint (@20 km)	2.8 km (10.7-19.35 GHz),1.5 km (37.1 GHz),0.6 km (85.5 GHz)
CoSMIR H+V (Radiometer)	37, 89, 165.5, 183.3+/-1, 183.3+/-3, 183.3+/-8 GHz (scanning)
Footprint (@20 km	1.4 km
HIWRAP (Radar)	13.91 GHz, 35.56 GHz (dual-pol. (LDR); nadir pointing)
Footprint (@20 km)	1 km Ku / 420 m Ka (2.9^{o} Ku, 1.2^{o} Ka)
EXRAD (Radar)	9.4 GHz (nadir); 9.6 GHz (scanning; 25 km swath@20 km alt.)
Footprint (@20 km)	1.2 km (3^{o} beamwidth)
CRS (Radar)	94.15 GHz (nadir pointing)
Footprint (@20 km)	~0.16 km (0.45^{o} x 0.47^{o} beamwidth)

The AMPR and CoSMIR radiometers will span multiple GMI and GPM constellation frequencies from 10 to 183 GHz (Table 5). For IPHEX the HIWRAP will operate as a nadir-staring instrument due to engineering constraints. The CoSMIR radiometer can perform conical and cross-track scanning nearly simultaneously, and the AMPR is a cross-track scanning radiometer. The full scanning capability (which will include a nadir sampling) of the CoSMIR and AMPR radiometers will be employed for IPHEX in order to more fully investigate the utility of dual-polarimetric scattering properties of precipitation (in particular the ice phase) in retrieval algorithms. The CRS is a dual-polarized nadir-viewing W-band Doppler cloud-radar. The EXRAD can scan conically at 35 degree incidence angle or cross-track and also has a nadir beam, collectively allowing high resolution precipitation retrievals and three-dimensional wind mapping within a 25 km swath.

4.2.2 University of North Dakota Citation

The UND Citation will serve as the in situ microphysics sampling platform with a primary emphasis (though certainly not exclusive of mixed-phase and/or rain) placed on the ice phase at altitudes between the melting level and cloud top altitudes well suited to its operating ceiling of ~12 km.

The Citation data will serve as a reference microphysics data set for assessing the scattering properties of ice viewed within the swath of both the ER-2 radiometer and radar and for validating hydrometeor retrievals provided by ground-based polarimetric radars. As such, microphysical data collections will be conducted in close coordination with the NASA ER-2 high altitude aircraft carrying nadir-viewing radar and radiometer instrumentation.

Table 6- UND Citation Microphysics Instrumentation

Instrument	Measurement
King	Cloud liquid water
PMS 2D-C/2D-S	Cloud and precipitation particle spectra
HVPS-3	Precipitation spectra to large sizes
CPI	Cloud particle imager, High resolution ice crystal and cloud-droplet imaging
CSI	Cloud Spectrometer and Impacter, Total Water (ACE)
CDP	Cloud Droplet Probe, cloud particle spectra
Nevzorov	Total water content
Rosemount icing probe	Supercooled water
CN	Aerosols (CN/CCN)

The Citation will carry a standard suite of meteorological instruments (T, p, humidity) together with microphysical instrumentation (Table 6) consisting of 1D and 2D PMS (C, P) probes, liquid water content probes (e.g., forward scattering spectrometer probe, King), and ice and condensation nuclei probes. Particle size distributions (PSD) from cloud to precipitation particle sizes will be measured with a combined PMS 2D-C and SPEC 2D-S probe and a SPEC HVPS-3 high-volume precipitation spectrometer probe. PSDs measured by these probes will cover the particle diameter range from a minimum of about 10 microns (depending on the probe and the aircraft true airspeed) to larger than 1 cm. The 2D probe data will be processed objectively to remove artifacts produced by shattering on the probes' leading edges (Korolev probe tips are used to further mitigate the shattering). The PSD of small particles, those with diameters from 2 to 50 microns, will be measured and imaged using the DMT Cloud Droplet Probe (CDP) and SPEC Cloud Particle Imager (CPI), respectively. The condensed water content—liquid plus solid—will be measured using the Nevzorov and Cloud Spectrometer and Imager (CSI) probes. Liquid water contents will be measured with a King-type hot wire probe above a threshold value of about 0.05 g m^{-3}. Supercooled liquid water will be detected using a Rosemount Icing (RICE) Probe. The RICE probe can confidently detect a liquid water content of only 0.02 g m^{-3} (which will be important for stratiform region microphysics). Background and in situ aerosol measurements will be made using a CN probe. These measurements will be collected in the near cloud environment and updraft air. Cloud vertical motions will be derived from the Citation gust probe.

4.2.3 Flight Plans

Several multiple-aircraft flight plans will be conducted during IPHEX with some situational variation to be expected based on evolving PMM needs, sampling requirements, air traffic control, and conditions on site. Generalized flight pattern "archetypes" are shown in Figure 16.

These patterns emphasize highly-coordinated linear stacked sampling in and around precipitation systems. The primary modules address precipitation organized by orography, a land module for unorganized precipitation, an ocean module for sampling offshore of the Carolinas, a land-surface pattern, and a GPM-core satellite under flight (note that under flights can technically be done with any of the modules as required).

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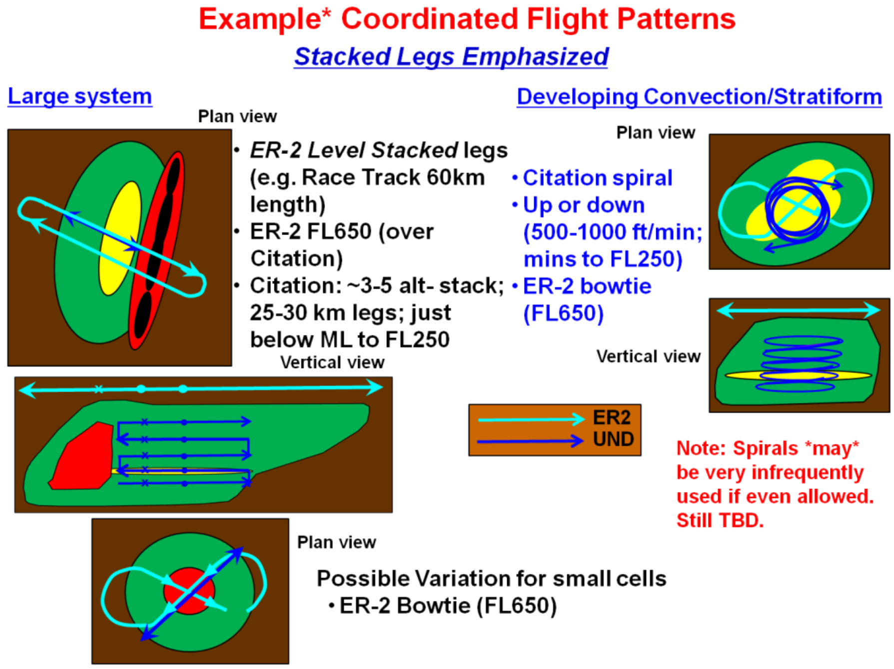

Figure 16 - Conceptual diagrams of three *possible* flight patterns to be executed during IPHEx: Top left- primary/priority sampling "racetrack" pattern in MCS or broad precipitation coverage conditions by the ER-2 (light blue) and Citation (dark blue) oriented *along ground-based radar radials*; Top Right/Bottom-Left- ER-2 and Citation or Citation-only profiling using Citation spiral pattern emphasizing vertical structure of PSD (melting layer included). Note that the spiral pattern is included but may only be infrequently used, if at all, due to air traffic issues. Note sampling outside of the precipitation system by ER-2 in primary racetrack pattern.

The priority orientation depicted in Fig 16 emphasizes stacked sampling along a radial extending from ground radars (NPOL/D3R and NOXP) where/when possible. For the primary flight pattern the ER-2 is situated in a racetrack containing one leg over the Citation and oriented along a ground radar radial while the other ER-2 leg is used for data collection during repositioning. In this fashion maximum data collections possible with the ER-2 as opposed to data losses during long turns if on single legs. Note that in addition to sampling precipitation, the ER-2 will also make occasional samples both ahead of and/or behind convective systems to enable sampling of surface radiative characteristics, and also execute fixed land-surface emission/scattering "ladder" pattern flights on clear days of opportunity (Fig. 12). Similarly, the UND Citation will independently collect sub- and ambient-cloud environment aerosol characteristics independent of flight leg coordination with the ER-2. Derivatives (e.g., changing orientation etc.) of the flight legs discussed below, for the individual aircraft, can be applied in these situations.

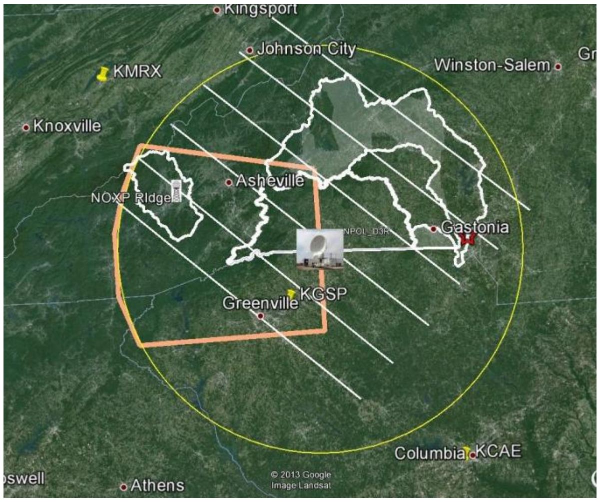

Figure 17. Example clear-air pattern to be flown by NASA ER-2. White lines indicate individual flight legs that are ~200 km long and separated by ~30 km. Locations of the NPOL radar and NOXP radars are indicated as is the dual-aircraft focus region (orange line), and watersheds of interest.

Individual ER-2 (Citation) flight legs in the Figures 16 represent horizontal distances on the order of 50–75 (25-40) km with endpoints that will generally be translated with the particular system being sampled (i.e., system relative sampling). The ER-2 will sample at a fixed altitude (nominally 20 km). The Citation will strongly focus on vertically stepped sampling to provide profiles of particle characteristics in the ice and mixed-phase (e.g., melting level) regions of precipitation, to include the liquid base of the melting level for vertical continuity of the melting process. Vertical separation of the Citation flight legs, when desired, will be on the order of 1- 2 km. It is recognized from the outset that the Citation will not be able to penetrate the deepest cores of convection and thus the patterns emphasize sampling in weaker embedded convection (< 40 dBZ, coalescence processes and cloud water) and broad stratiform precipitation (e.g., Fig. 16). Prior to execution of the coordinated flight legs with the ER-2, it is desirable to have the Citation ascend through and profile sub-cloud layer thermodynamics and also limited profiles of aerosols (via CN probe) as the aircraft approaches the precipitation system.

In certain situations (especially those associated with stronger convection). It will be desirable to orient the ER-2 flight legs relative to the convection so that the endpoints extend past the location of deep convection while the Citation leg endpoints remain within the weaker stratiform precipitation.

Collectively, the primary objectives of the GPM GV flight plans for IPHEx are to accomplish:

1. Validation and improvement of GPM GMI and DPR algorithms using collocated ground and airborne dual-frequency/polarimetric radar vertical structure and radiometer brightness temperatures in stratiform and weak convection

2. Well-coordinated profiling of *in situ* microphysical properties, with particular emphasis placed on stratiform precipitation, weaker convection and the ice phase.
3. Verification/calibration of ground-based multi-parameter radar retrievals
4. Selected detailed sampling of the melting layer profiles and microphysics
5. Sampling of pre- and post-storm land surface characteristics at all radar and radiometer frequencies for backscatter cross-section and surface emissivity studies.

ACE/RADEX Flight Plans

RADEX is the Radar Definition Experiment and is presently planned in 2 phases, RADEX-14 in Spring 2014 and RADEX-15 in Winter 2015/16. These activities are intended to support algorithm development and proof-of-concept toward formulation of the Aerosol, Cloud and Ecosystems (ACE) mission concept described in the Earth Science Decadal Survey (NRC, 2007) and presently in pre-formulation. Specifically, RADEX seeks to acquire high quality data sets corresponding to cloud targets of high interest under conditions most favorable to algorithm development, e.g., ocean background and minimized cloud heterogeneity. RADEX-14 heavily leverages IPHEx and will occur coincident with IPHEx. No additions were made to the planned IPHEx ER-2 payload, i.e., multi-frequency Doppler radar, and scanning microwave radiometers from low to high frequency. When appropriate, IPHEx flight lines will be optimized for RADEX applications. During IPHEx, RADEX-14 will also conduct 2 dedicated ER-2 flights on non-interference basis. RADEX-14 will have support of UND Citation for *in-situ* measurements of cloud physics profiles during these dedicated over-water flights, similar to the plan for IPHEx. A key science objective of ACE is to characterize the processes that convert cloud water and ice into precipitation, and ultimately the effects of aerosols on those processes. To adequately describe these cloud processes, it is necessary to collect both active and passive multi-frequency microwave measurements. The IPHEx ER-2 payload is ideally suited for this purpose. The ACE team will be able to use these measurements, along with the *in- situ* observations by the Citation, to *explore the degree to which such processes can be observed and the degree of measurement complexity necessary to accomplish this task.* Characterizing cloud and precipitation physical properties inside the clouds requires radar, and specifically multi-frequency radar. IPHEx offers a first opportunity to acquire such observations at 4 radar frequencies, including W, Ka and Ku bands, and X-band, along with microwave radiometer observations across a broad range of frequencies. These test data sets will be highly valuable in demonstrating and evaluating the full capabilities of multi-frequency Doppler radar to describe the internal structure of cloud systems and the processes that are typically hidden from more conventional remote sensing. Target cloud systems include precipitating stratiform ice clouds, cirrus clouds, and possibly shallow warm convective clouds developing into the middle troposphere.

5. IPHEx Hydro-GV Testbed- H4SE

The H4SE intercomparison study will allow us to assess the quality and utility of various QPE and QPF products, and to understand present-day capabilities of hydrologic models and their performance in regions characterized by different hydrologic regimes in the light of current QPE and QPF skill. This will serve as a baseline for assessing the utility of GPM precipitation products in the future as they become available. Other modeling and analysis activities associated with IPHEx include detailed attribution of uncertainty in satellite rainfall retrieval to uncertainty in hydrologic states, data-assimilation studies to investigate the integration of satellite-based rainfall estimates, and numerical weather prediction models to improve place-based QPE for streamflow prediction and flood warning.

The work plan for H4SE is organized in four phases as follows:

Phase 1 – Generation and documentation of 7-year data sets (2007-2013) including atmospheric forcing, time-varying LULC parameters and states (land-use and land-cover), ancillary data including soil properties, topography, and precipitation (Stage IV downscaled to 1 km resolution) . The data are available at http://iphex.pratt.duke.edu including documentation (Jing and Barros 2013a and 2013b, Nogueira and Barros 2014). These data sets are provided at 1km ×1km spatial resolution and at hourly temporal resolution. H4SE participants are expected to rely on these data sets to set up, test and calibrate their hydrologic models. Participants are also asked to select basins of interest for model evaluation. Meanwhile the East and West Fork of the Pigeon River basins as well as Cataloochee Creek, a USGS Benchmark watershed, are suggested are primary intercomparison basins due to their location in the Pigeon River Basin, lack of regulation and the existence of dense ground-observations in the region. The Upper Catawba and the Upper Yadkin are also suggested as core basins due to high density of HMT-SEPS observations in place, soil moisture sampling sites (see Appendix B), and because these basins will be on the planned flight lines for soil moisture measurements with SLAP. The goal is to achieve hydrologic modeling readiness by 4/30/2015.

Phase 2 –4/30/2014 -4/31/2014.

This is the phase during which tests for the H4SE-OT (Operational Testbed) will be conducted. During the IOP, NU-WRF's (Tao et al. 2013, NASA GSFC) high-resolution real-time forecasts will be used to support aircraft operations from 1 May-15 June 2014.

Specifically, up to 48-hrs forecast results will be delivered for the daily morning briefing. The NU-WRF (Table 7) will be implemented using three nested grids (Fig. 18, Table 8). NU-WRF atmospheric forcing 2D fields required for H4SE (Table 9) produced by NASA GSFC will be downloaded and mapped into the same grids used for the data sets in Phase 1 at the same spatial resolution and at 5-min time-step. If necessary, pending a survey of participants, hourly data sets will be produced using the same integration algorithms as in Phase 1. Post IOP, a series of retrospective simulations will be conducted with NU-WRF with the integration of available observational and reanalysis datasets to identify model error and improve understanding on precipitation and hydrological processes. Retrospective simulations will be validated against observations and compared with previously produced real-time forecast datasets.

Table 7 - Physics schemes for NU-WRF real-time forecast

Microphysics	Goddard 4-ice scheme
Cumulus	Grell-Devenyi Ensemble
Radiation	Goddard scheme
PBL	MYJ
Surface	Noah
Surface layer	Eta

The NU-WRF precipitation forecasts will be used as the Level 1 QPF benchmark for the operational forecasts. We anticipate that in addition to NU-WRF, other atmospheric forcing and Level 2 QPF will be made available based on WRF simulations using alternative physics options for specific case-studies (Duke/GSFC) and using RAMS (U. Connecticut). Modelers are also encouraged to use Level 2 QPF in the operational forecasts as QPE/QPF benchmarking is the central objective of H4SE. Stage IV precipitation (merged radar and raingauge observations) will be collected as soon as is released by the NWS and will be used as the Level 1 QPE reference.

In addition, MRMS precipitation and reflectivity composites (Level 2 QPE) will be available from NSSL in near-real time every 2-5 min over the inner domain for NU-WRF. Modelers can integrate the MRMS QPE with the NU-WRF QPF as it becomes available to update their hydrologic forecasts for each day. The MRMS data for each day during the IOP will be retrieved and stored for post-IOP retrospective studies. Finally, other QPE products from project participants (e.g. Byron systems) and TRMM and GPM observations will also be used during the IOP as they become available.

Table 8 - Domain Geometry for NU-WRF real-time forecast

Horizontal grids	Three nested domains (Fig. 10) : D1 -9km (386x353), D2-3km (601x553), and D3-1km (751x67)
Lat, Long Grid SW and NE Corners	D1: (20.74454N, -102,36668E) and (49.019N, -63.87517E) D2: (28.18819N, -91.57446E) and (43.06697N, -71,56013E) D3: (32.69919N, -87.07486E) and (38.70804N, -78.73277E)
Vertical grids	60 layers
Time-step	30 secs
Initial & Boundary Conditions	GFS at 0.5 º spatial resolution , every six hours

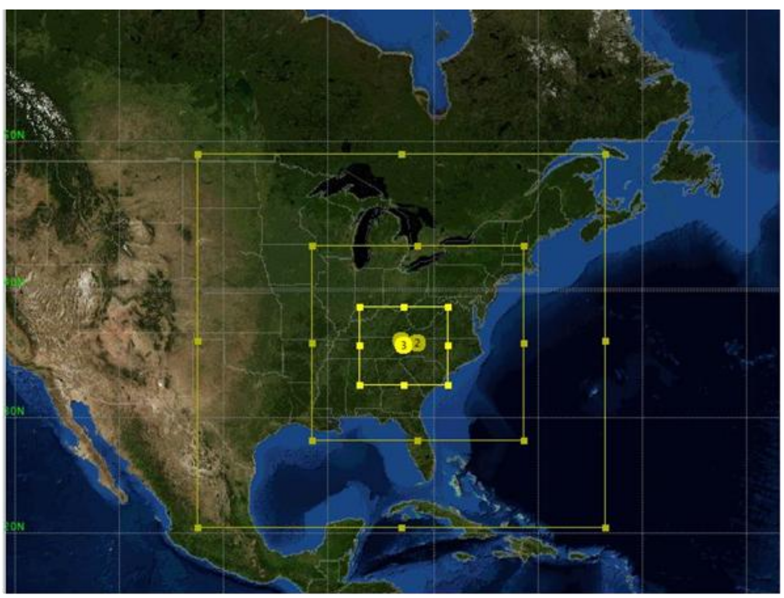

Figure 18 - NU-WRF nested modeling domains for IPHEx as described in Table 8.

In addition to NU-WRF, simulations over a smaller domain but meeting the same criteria of spatial and temporal resolution of resolution, simulations using RAMS-ICLAMS will also be made available during the IOP from U. Connecticut (please see Appendix C for details and references).

In summary, four – seven QPE and QPF 2D fields will be available to modelers to conduct operational hydrological forecasts for H4SEduring the IOP as summarized in Table 10. Modelers are encouraged to use all available data for their forecasts.

Table 9 – Forcing fields (24h/48h) needed for H4SE hydrological forecasts.

Input fields required#	**Spatial Resolution**	**Temporal Resolution***	**Units**
Land surface albedo	1km×1km	Hourly/5 min	---
Specific humidity	1km×1km	Hourly/5min	---
Atmospheric temperature (2m or/and 10m above the surface)	1km×1km	Hourly/5min	K
Atmospheric pressure (2m or/and 10m above the surface)	1km×1km	Hourly/5 min	mb(hPa)
Wind velocity (2m or/and 10m above the surface)	1km×1km	Hourly/5 min	m/s
Incoming/downward longwave radiation at surface	1km×1km	Hourly/5 min	W/m^2
Incoming/downward shortwave radiation at surface	1km×1km	Hourly/5 min	W/m^2
Precipitation Accumulations	1km×1km	Hourly/5 min	mm

* Hourly resolution is the baseline requirement; Finer temporal resolution is more desirable. All values except precipitation are instantaneous. Precipitation values are accumulations at the reference time for the next hour, or for the next five minutes

Here just the forcing fields are listed. Other outputs from forecast model can be used for comparison with hydrological model results, including sensible heat flux, latent heat flux, ground heat flux, soil moisture and soil temperature.

Table 10 – Precipitation Products Summary. Benchmark levels are indicated in ().

QPF		**QPE**	
NU-WRF **(L1)**	48hr lead-time every day by 8 AM	StageIV Downscaled **(L1)**	5min
RAMS-ICLAMS **(L2)**	24hr lead-time Every day by 9 AM	MRMS **(L2)**	2-5 min
WRF-Duke **(L3)**	Selected Events	Satellite **(L3)** (GPM and TRMM)	3 hourly and instantaneous
Data-Assimil **(L3)**	Selected Events	Byron **(L4)**	
		Huan Wu **(L5)**	

Phase 3 – 5/1/2014 -6/15/2014

Participants will submit in advance a list of the watersheds where they will be running the hydrological forecasts. A list of forecast points will be developed based on this information. During the IOP, each participant will submit streamflow forecasts at the forecast points for L1 QPF by 1PM EST. By 10 PM, modelers are asked to submit their ensemble of QPE-QPF combined forecasts as well as initial and ending 2D fields of soil moisture for the forecast basins. The forecast ensemble combinations for the various benchmark levels are summarized in Table 11. The minimum number of ensemble forecasts required is 3; the desirable number is 6. For specific events a maximum number up of QPE-QPF ensembles up to 17 can be anticipated. For each forecast point or watershed, the forecasts submitted will be combined for each day and the spatial fields of the residual ΔR (P-ΔSM = ΔR) and the basin integrated value of ΔR will be calculated. Forecast hydrographs, ΔR fields and ratios of basin integrated values (Q/P and ΔR/P) will be displayed for all models without attribution (using a code) and shared among participants. Protocols and Work Flow to carry out Phase 3 are detailed in Appendix D.

Table 11 – Daily ensemble hydrologic forecasts for each basin during H4SE. Cells in yellow indicate minimum required. Cells in Pink indicated highly desirable. Others will depend on data availability and are encouraged.

QPF	QPE-QPF	Additional
L1	**L1-L1** **L1-L2**	**L1-L3** **L1-L4**
L2		**L2-L1** **L2-L2**
		L2-L3 **L2-L4**
		L1-L5
		L2-L5
L3		L3-L1 L3-L2 L3-L3 L3-L4 L3-L5

Phase 4 – 6/15/2014 -10/15/2014

The results from the H4SE-OT will be integrated and analyzed and a synthesis manuscript co-authored by all participants will be prepared to report the research findings. Participants are invited to take up selected cases for retrospective analysis and simulations throughout the duration of the EOP. A second synthesis manuscript reporting on lessons learned and including uncertainty analysis is anticipated.

Leveraged Research Opportunities - IPHEx is open to the participation of scientists interested in leveraging research opportunities, or for educational purposes. Summaries of leveraged activities are collected under Appendix E.

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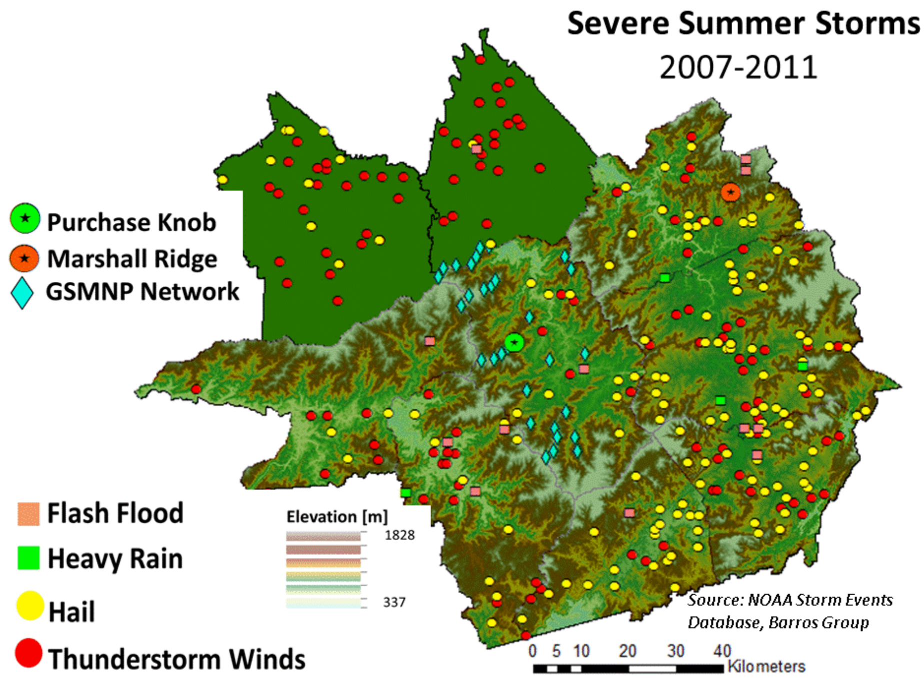
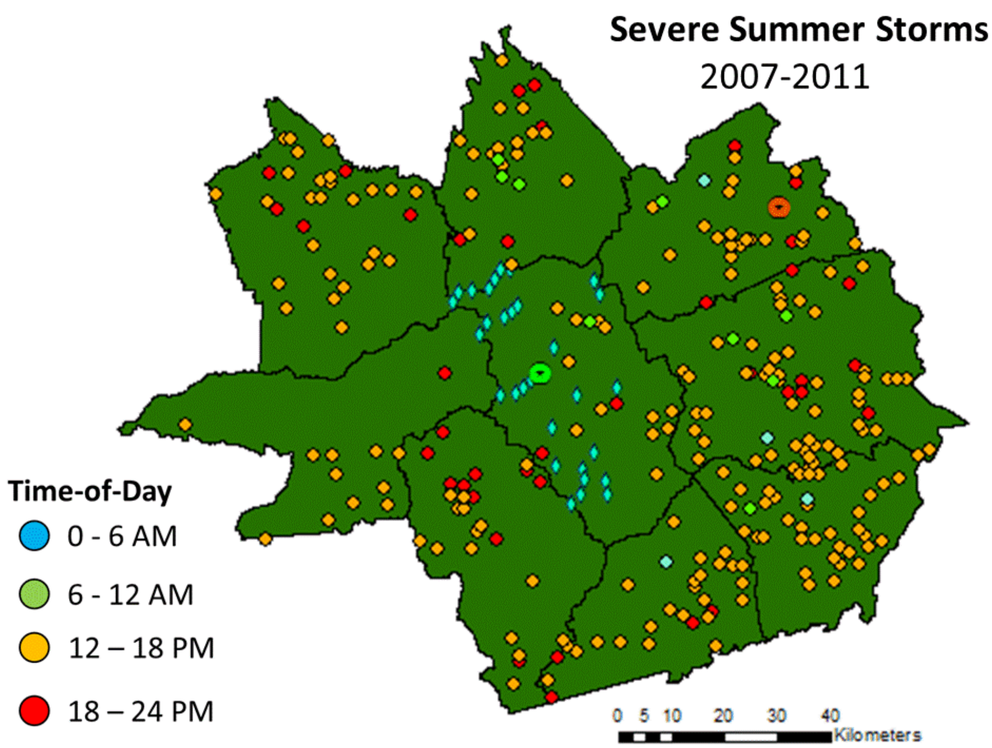
List of Participants

APPENDIX A - Climatology of Severe Storms





APPENDIX B - Soil Moisture Data sets for North Carolina

- ECONET: North Carolina Environment and Observing Network
  https://www.nc-climate.ncsu.edu/econet

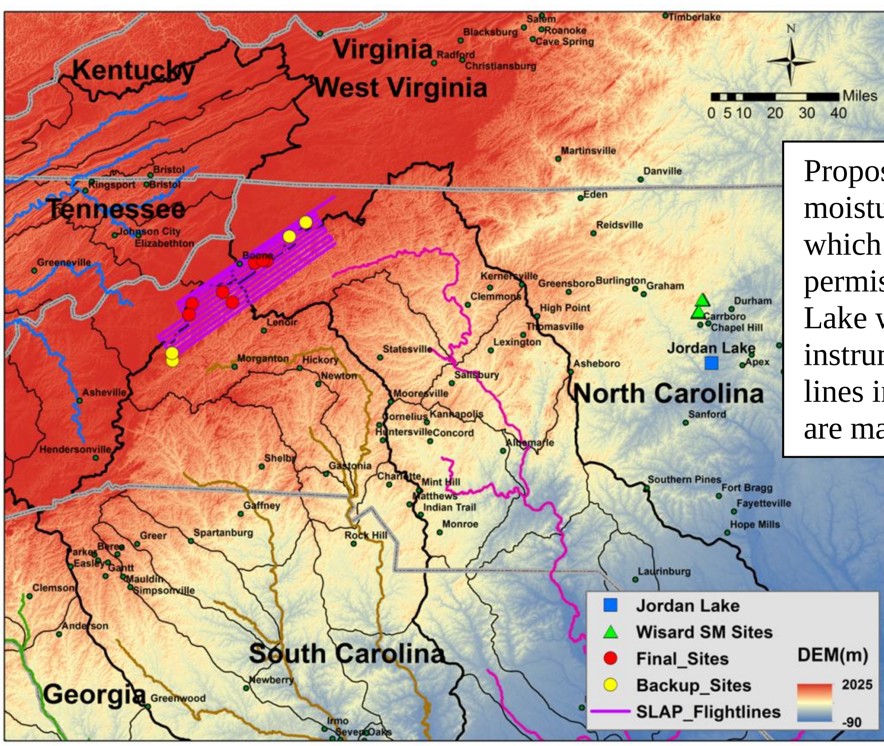
DB	NAME	LAT	LON	ELEV (ft)	INSTALL DATE
ECONET	AURO	35.36232	-76.7163	4	6/30/2000
ECONET	BEAR	35.46135	-82.35822	4219	7/27/2000
ECONET	BOON	36.2214	-81.6295	3254	9/20/2005
ECONET	BUCK	36.46955	-76.7609	25	9/20/2006
ECONET	BURN	35.91904	-82.28053	2702	12/17/2008
ECONET	CAST	34.32107	-77.91611	43	3/17/1983
ECONET	CLA2	35.59158	-78.45889	250	8/2/2003
ECONET	CLAY	35.66979	-78.4926	350	12/8/1978
ECONET	CLIN	35.02218	-78.28195	166	4/17/1984
ECONET	DURH	36.02896	-78.85851	332	11/12/2008
ECONET	FLET	35.42721	-82.55888	2067	6/18/1982
ECONET	FRYI	35.39357	-82.77427	5320	11/16/2004
ECONET	GOLD	35.37935	-78.0448	79	4/5/2002
ECONET	HAML	34.84207	-79.7384	336	11/27/2007
ECONET	HIGH	35.99	-79.97	910	4/11/2002
ECONET	JACK	35.18782	-79.68437	625	8/29/1985
ECONET	KINS	35.30288	-77.57306	95	6/10/1987
ECONET	LAKE	35.72816	-78.67981	382	5/12/1982
ECONET	LAUR	36.40232	-81.29711	3009	4/18/2000
ECONET	LEWS	36.1324	-77.17552	61	4/3/1979
ECONET	LILE	34.97043	-79.91771	456	5/18/2007
ECONET	MITC	35.7585	-82.2712	6200	6/26/2008
ECONET	NCAT	36.06733	-79.73447	792	2/23/2006
ECONET	NEWL	35.40981	-80.23748	585	10/22/2009
ECONET	OXFO	36.30339	-78.61662	500	5/1/1987
ECONET	PLYM	35.84887	-76.65058	20	7/20/1984
ECONET	REED	35.80712	-78.74412	420	10/14/1998
ECONET	REID	36.38152	-79.69982	858	5/19/1999
ECONET	ROCK	35.89295	-77.67996	88	5/19/1987
ECONET	SALI	35.69744	-80.62186	703	5/12/1982
ECONET	SILR	35.7043056	-79.5041889	614	10/24/2000
ECONET	SPRU	35.8996	-82.0582	2800	2/7/2013
ECONET	TAYL	35.9139	-81.19087	1167	11/6/2008
ECONET	WAYN	35.48752	-82.96768	2755	10/3/1987
ECONET	WHIT	34.41347	-78.7923	89	5/25/1984
ECONET	WILD	34.7658	-78.10117	56	9/25/2008
ECONET	WILL	35.83903	-77.09349	72	5/10/2000
ECONET	WINE	35.1731	-83.58097	5469	5/15/2002

- NOAA: Earth System Research Laboratory; Physical Sciences Division
  http://www.esrl.noaa.gov/psd/data/obs/datadisplay/index.php?ProjectID=7

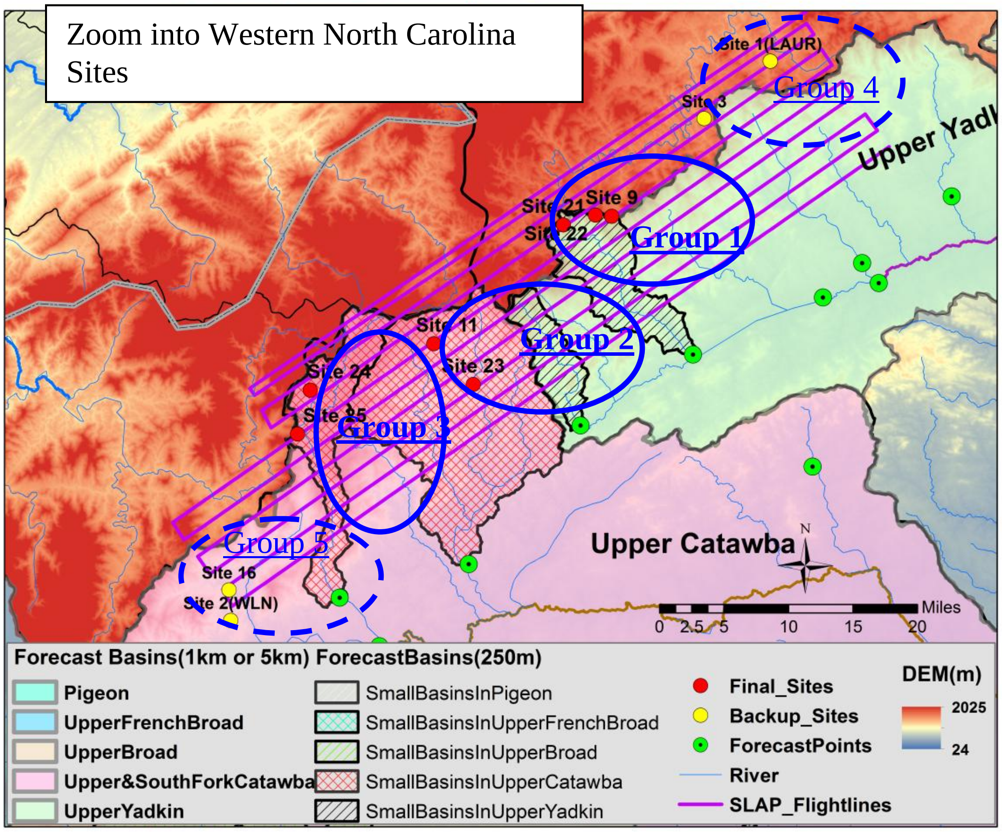
NAME	LAT	LON	ELEV (m)	INSTALL DATE	PROJECT
Brindletown	35.6423	-81.781	353	6/6/2013	Hydrometeorology Testbed - South East
Crooked Creek	35.5744	-82.1888	490	9/10/2013	Hydrometeorology Testbed - South East
Crossnore	36.0148	-81.93	1008	8/2/2013	Hydrometeorology Testbed - South East
Spruce Pine	35.9473	-81.995	833	8/3/2013	Hydrometeorology Testbed - South East
Table Rock	35.8397	-81.8332	350	8/3/2013	Hydrometeorology Testbed - South East
Woodlawn	35.7678	-82.04	520	8/2/2013	Hydrometeorology Testbed - South East
Asheville 13S	35.5505	-82.53	671	11/15/2000	NOAA
Asheville 8SSW	35.4989	-82.6098	663	11/15/2000	NOAA
Durham 11 W	35.9667	-79.9333	80	3/29/2007	NOAA

- SCAN USDA: Soil Climate Analysis Network
  http://www.wcc.nrcs.usda.gov/scan/
  USDA and ECONET http://www.ncagr.gov/research/locations.htm

NAME	LAT	LON	ELEV (m)	INSTALL DATE
Tidewater	35.86667	-76.65	6	10/1/1994



Proposed field sites for soil moisture ground validation, which require land-owner permission (in red). Jordan Lake will be used fro instrument calibration. Flight lines in the Western Piedmont are marked in pink.


Zoom into Western North Carolina Sites
Site 1(LAUR)
Group 4
Site 3
Upper Yadk
Site 21
Site 9
Site 22
Group 1
Site 11
Group 2
Site 24
Site 23
Site 25
Group 3
Group 5
Upper Catawba
Site 16
Site 2(WLN)
N
0 2.5 5 10 15 20 Miles
Forecast Basins(1km or 5km)
ForecastBasins(250m)
Pigeon
UpperFrenchBroad
UpperBroad
Upper&SouthForkCatawba
UpperYadkin
SmallBasinsInPigeon
SmallBasinsInUpperFrenchBroad
SmallBasinsInUpperBroad
SmallBasinsInUpperCatawba
SmallBasinsInUpperYadkin
Final_Sites
Backup_Sites
ForecastPoints
River
SLAP_Flightlines
DEM(m)
2025
24

APPENDIX C

Regional Atmospheric Modeling System/Integrated Community Limited Area Modeling System (RAMS/ICLAMS) –University of Connecticut (Marina Astitha)

RAMS/ICLAMS (Solomos et al. 2011) is an integrated air quality and chemical weather modeling system, based on the RAMSv6 (Pielke et al. 1992; Cotton et al. 2003), that directly couples meteorological fields with air quality components, and includes gaseous, aqueous, aerosol phase chemistry and partitioning of CCN, GCCN, and IN as predictive quantities. The two-moment bulk microphysics scheme of RAMS/ICLAMS includes seven condensate species (cloud droplets, rain droplets, pristine ice, snow, aggregates, graupel, and hail) and vapor, and prognoses both the mixing ratio and number concentration of each hydrometeor (Meyers et al. 1997). The model includes an explicit cloud droplet nucleation parameterization scheme (Nenes et al. 2002; Fountoukis and Nenes 2005) and has been widely used for atmospheric research during the last two decades. The explicit cloud scheme provides a comprehensive microphysical link between aerosols and clouds and computes droplet number based on the parcel framework, and solves for the maximum super-saturation that develops given a set of cloud-scale dynamics (temperature, pressure, and vertical wind component) and aerosol properties (number concentration, size distribution, and chemical composition). For this work, the RAMS/ICLAMS will be used without the full chemistry option. However, we might include the natural species production and transport (desert dust and sea salt) that affect the radiation and cloud microphysical processes more significantly.

Table C1 - Physics schemes

Cloud microphysics	Warm rain processes; Five ice condensate species; Two-moment bulk scheme; Explicit cloud droplet activation scheme
Cumulus	Kain-Fritsch
Radiation	Rapid Radiative Transfer Model (RRTM)
Vertical coordinates	Terrain following height coordinates
Surface Layer	Soil – vegetation – snow parameterization (LEAF-3)

Table C2 – Domain Geometry

Horizontal Grids	Three nested domains: G1(195x187, 20km), G2(272x217, 4km), G3(302x250, 1km)
Vertical Grids	60 layers
Model time step	30sec
Initial Conditions	GFS 0.5deg
Boundary Conditions	SST daily, NDVI, topography, vegetation, soil texture (FAO)

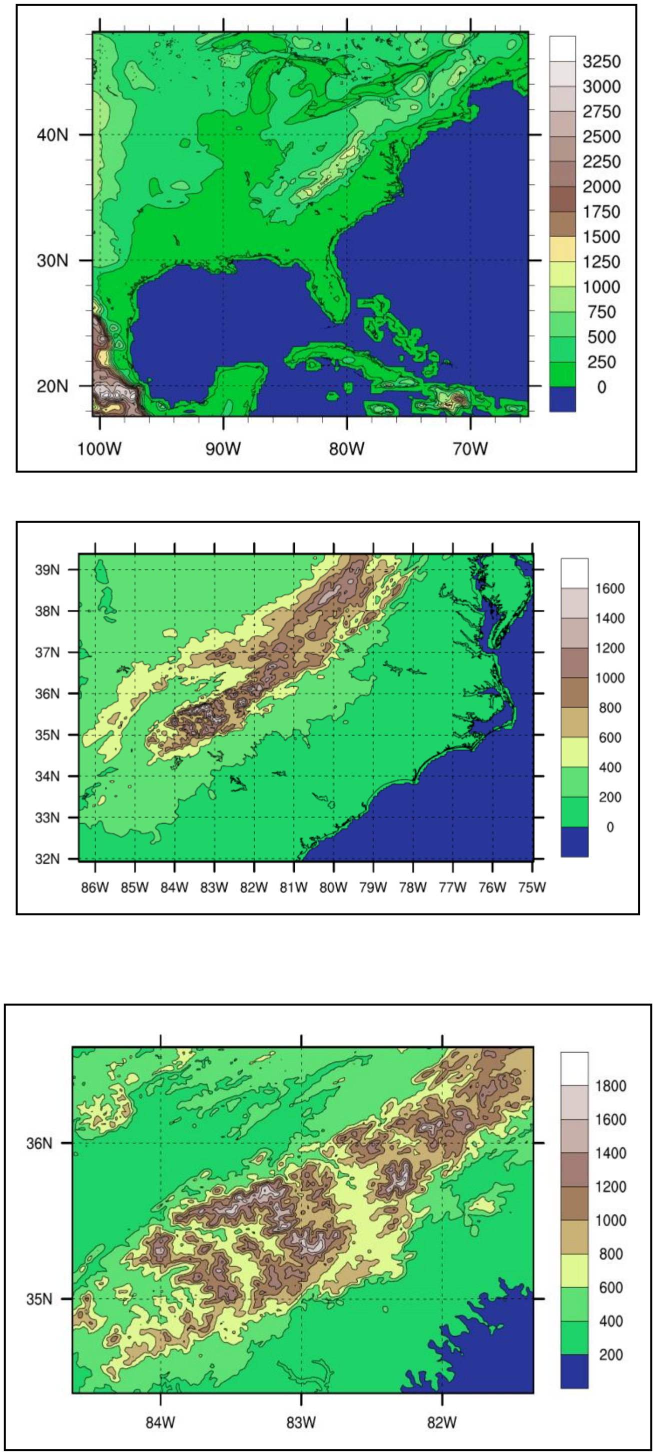


Figure C1 - Gridded domains for the IPHEX experiment with topographic heights (m). Top: coarse grid (20km spatial resolution). Middle: 1st nested grid (4km spatial resolution). Bottom: 2nd nested grid (1km spatial resolution).

APPENDIX D

H4SE IOP Streamflow Operational Plan

D1. Framework - Every day, for each basin, also referred to as Forecast Point (FP), the following metrics will be produced: 1) a 24 hr **same-day Forecast**, **F** ; and 2) a 24hr **Hindcast, H**. Previous **Observations, O** for the same 24hr period will also be collected.

Table D1 - Table Proposed Forecast Points- Small basins and Headwaters in NC.

Point	Site No.	Station Name	Latitude	Longitude	HUC Code	Drainage Area(mi²)	Basin
1	03460000	CATALOOCHEE CREEK NEAR CATALOOCHEE	35.667500	-83.073611	6010106	49.2	Pigeon
2	03455500	WEST FORK PIGEON RIVER ABOVE LAKE LOGAN NR HAZELWOOD	35.396111	-82.937500	6010106	27.6	
3	03456500	EAST FORK PIGEON RIVER NEAR CANTON	35.461667	-82.869722	6010106	51.5	
4	03439000	FRENCH BROAD RIVER AT ROSMAN	35.143333	-82.824722	6010105	67.9	Upper French Broad
5	03441000	DAVIDSON RIVER NEAR BREVARD	35.273056	-82.705833	6010105	40.4	
6	02149000	COVE CREEK NEAR LAKE LURE, NC	35.423333	-82.111667	3050105	79	Upper Broad
7	02150495	SECOND BROAD RIVER NR LOGAN	35.404444	-81.872500	3050105	86.2	
8	02137727	CATAWBA R NR PLEASANT GARDENS	35.685833	-82.060278	3050101	126	Upper Cataw ba
9	02138500	LINVILLE RIVER NEAR NEBO	35.794722	-81.89	3050101	66.7	
10	02140991	JOHNS RIVER , ARNEYS STORE	35.833611	-81.711944	3050101	201	
11	02111000	YADKIN RIVER, PATTERSON,	35.990833	-81.558333	3040101	28.8	Upper Yadkin
12	02111180	ELK CREEK AT ELKVILLE	36.071389	-81.403056	3040101	50.9	

The 24hr casting period on Day X corresponds to 0005-2400 UTC for the same day.
For each FP, metrics to be produced include: hydrograph, peak flow, return period of peak flow with respect to historical record, time-to-peak, volume of runoff. Proposed Forecasts Points are summarized in Tables D1 and D2 and mapped in Figs. D1 and D2.

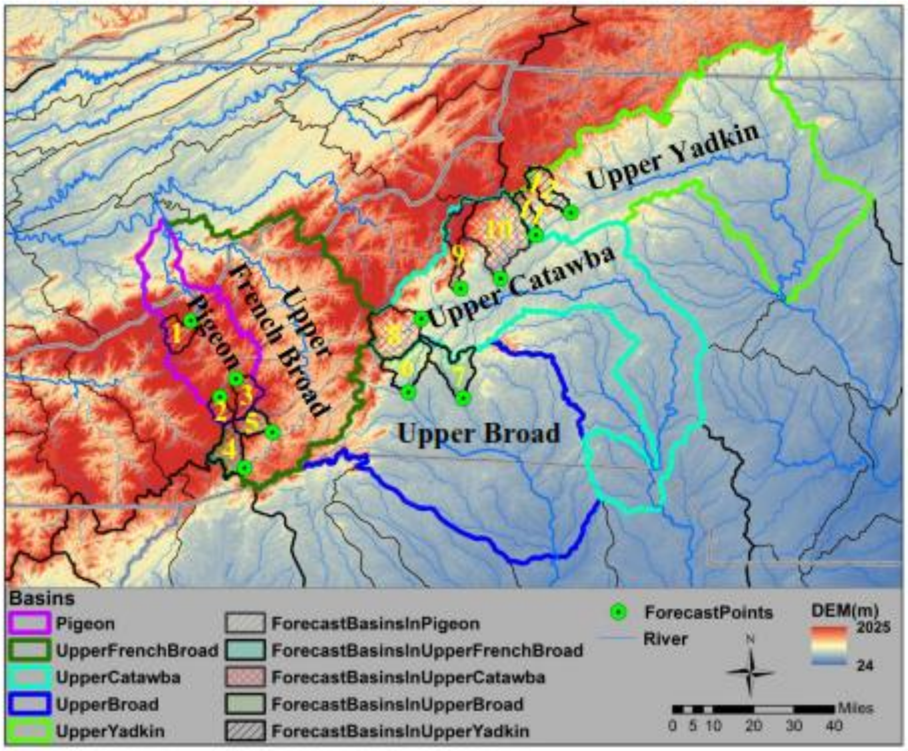


Figure D1 - Forecast Points: Proposed headwater (small) basins.

Table D2- Proposed Forecast Large Basins

Basin	Basin Name	HUC Code	Drainage Area(km^2)	Forecast Points within the Basin
1	Pigeon River Basin	06010106	1825	9
2	French Broad River Basin	06010105	4817	12
3	Upper Broad River Basin	03050105	6401	15
4	Upper Catawba and South Fork Catawba River Basin	03050101 03050102	7842	21
5	Upper Yadkin River Basin	03040101	6353	12

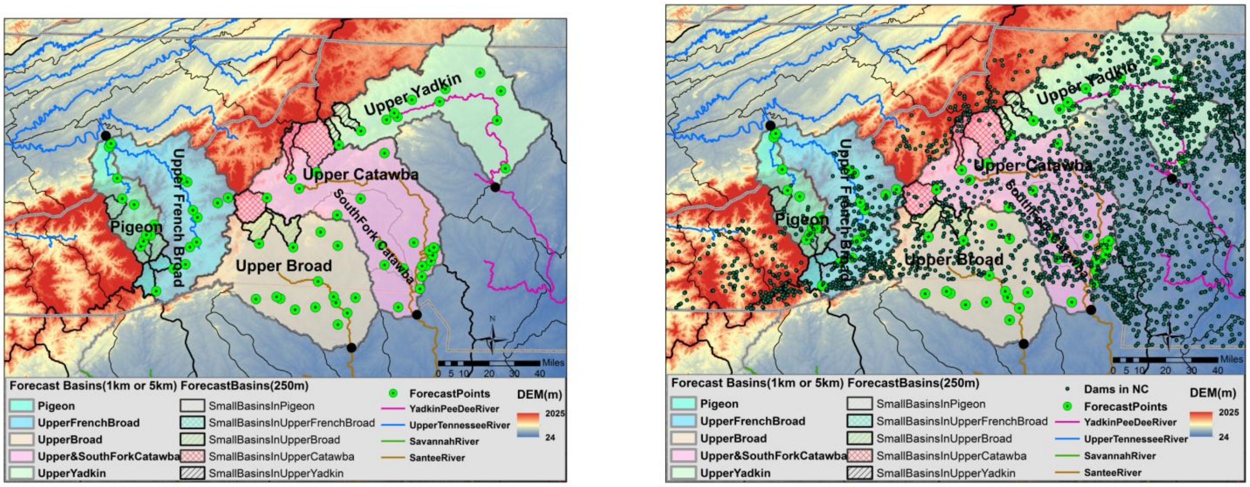


Figure D2 - Forecast Points - Left Panel: Proposed large basins. Right Panel: same as left panel but with dam sites marked.

Forecast Points selected by each participant model are shown in Table D3.

Table D3 - Hydrologic Models

Model (Resolution)	**FP- Headwaters**	**FP- Large Basins**	**FP-Gridded Points**
Duke (250m)	Table D1, Fig. D1		
Duke (1-5 km)		Table D2, Fig. D2	
NSSL-FLASH/CREST		Table D2, Fig. D2	**X**
GSFC			

D.2 Forcing – Operational Mode

Atmospheric Forcing and QPF and QPE for the forecasts and hindcasts are summarized in Table D4. Atmospheric forcing from NU-WRF and RAMS/ICLAMS (on a smaller domain) will be post-processed and made available to everyone at the Duke IPHEx website approximately by 11:30 AM EST every day (depending on availability).

1.1 Meteorological + Hydrometeorological Forecasts

- *NU-WRF*
- *RAMS/ICLAMS*

1.2 Precipitation Observations

- MRMS gauge corrected – 1 km×1 km, hourly: MRMS*

Table D4 - Hydrologic Model Forcing

Model	Same Day Forecast F	Next Day Hindcast H
Duke (3DLSHM-GW)	NU-WRF	NU-WRF+MRMS*
NSSL (FLASH/CREST)	RAMS/ICLAMS	
GSFC		

Hindcasts are viewed as the forcing of Same-Day Forecasts with hourly precipitation replaced by MRMS* (see Section D.2)

1.3 Forcing – Case Studies after IOP

1.3.1 Meteorological + Hydrometeorological Analysis and DA

RAMS/ICLAMS: Meteorological simulations with enabled feedback of natural aerosols on cloud/precipitation (sea salt, dust).

1.3.2 Additional Precipitation Observations

- *Stage IV*
- *RFC best QPE (will be available with some latency)*
- *Satellite Products*
- *Other (Byron Systems, NWS, etc.)*

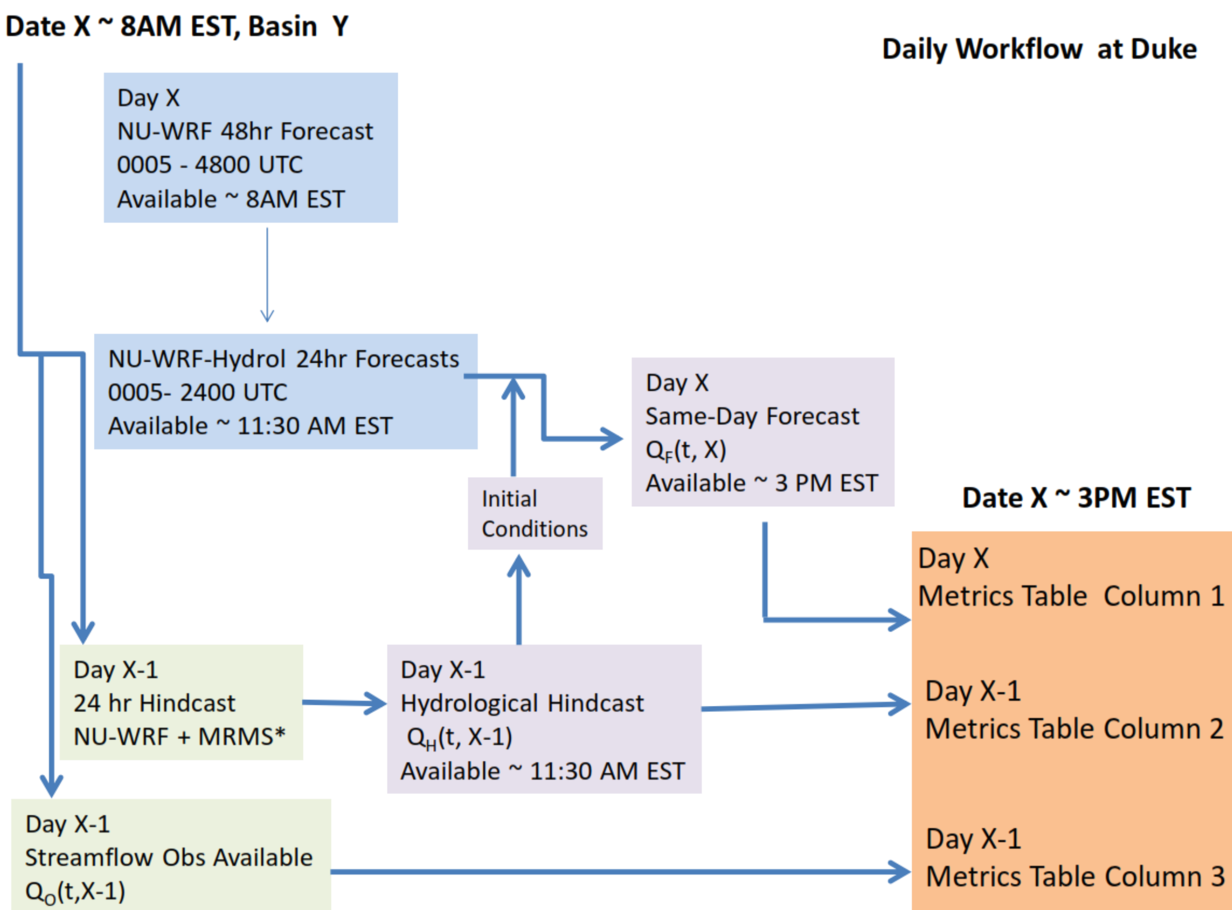
D.3 - Operational Forecasts and Assessment

We propose to publish the metrics on a daily basis at 3PM EST. The Metrics Matrix beginning on a hypothetical Date (Day X-1) and the sequence by which it can be filled (metric is "in" on the day corresponding to the color) is presented in Fig. D3. Companion graphics are shown in Fig. D4. The nomenclature for the proposed assessment metrics is as follows:

Metrics

1. Hydrograph	1.F- Q_F(t,Day)	1.H- Q_H(t,Day)	1.O- Q_O(t,Day)
2. Peak flow	2.F- $^{P}Q_F$ (Day)	2.H- $^{P}Q_H$ (Day)	2.O- $^{P}Q_O$ (Day)
3. Return Period of Peak Flow	3.F- $^{P}TR_F$(Day)	3.H- $^{P}TR_H$(Day)	3.O- $^{P}TR_O$(Day)
4. Time to Peak	4.F- $^{P}T_F$ (Day)	4.H- $^{P}T_H$ (Day)	4.O- $^{P}T_O$ (Day)
5. Volume	5.F- Vol_F (Day)	5.H- Vol_H (Day)	5.O- Vol_O (Day)

The workflow for producing daily forecasts and assessment metrics at Duke will follow the chart below.


Date X ~ 8AM EST, Basin Y
Daily Workflow at Duke
Day X
NU-WRF 48hr Forecast
0005 - 4800 UTC
Available ~ 8AM EST
NU-WRF-Hydrol 24hr Forecasts
0005- 2400 UTC
Available ~ 11:30 AM EST
Day X
Same-Day Forecast
$Q_F(t, X)$
Available ~ 3 PM EST
Initial
Conditions
Date X ~ 3PM EST
Day X
Metrics Table Column 1
Day X-1
24 hr Hindcast
NU-WRF + MRMS*
Day X-1
Hydrological Hindcast
$Q_H(t, X-1)$
Available ~ 11:30 AM EST
Day X-1
Metrics Table Column 2
Day X-1
Streamflow Obs Available
$Q_O(t,X-1)$
Day X-1
Metrics Table Column 3

IOP Operational Results – Metrics at 3PM EST

Date		Basin Y	Model		
0000-2400 UTC			F	H	Obs
Day X-1	Metrics	1	in	in	in
		2	in	in	in
		3	in	in	in
		4	in	in	in
		5	in	in	in
Day X	Metrics	1	in	in	in
		2	in	in	in
		3	in	in	in
		4	in	in	in
		5	in	in	in
Day X+1	Metrics	1	in		
		2	in		
		3	in		
		4	in		
		5	in		
……					

Figure D3 – Assessment matrix for a selected Forecast Point Y, on Day X+1 at 3Pm EST.

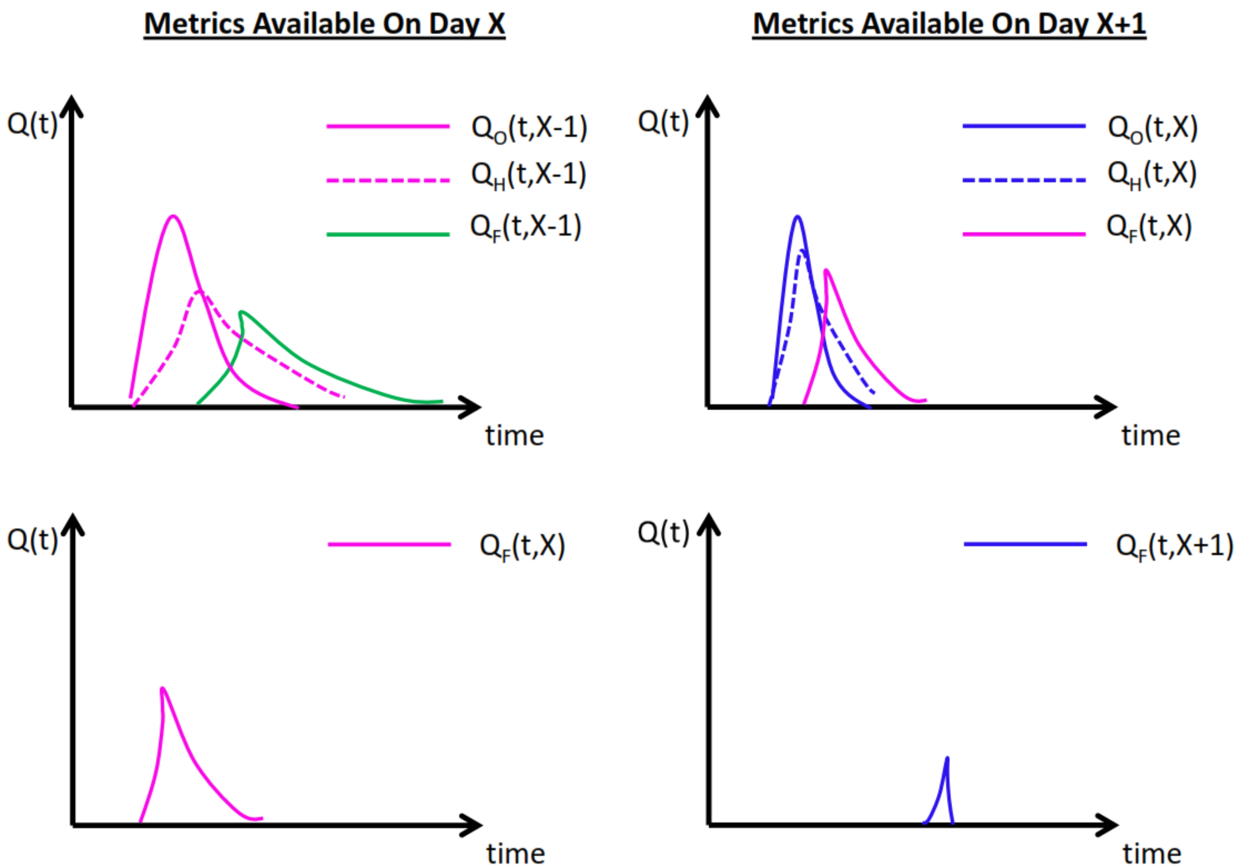


Figure D4 – Hypothetical example of assessment graphics displaying observed, hindcast and forecast hydrographs for FP Y on two different dates.

APPENDIX E

E.1 Hydrologic science objectives during IPHEX

Jonathan J. Gourley (NSSL)

26 March 2014

Participants from the National Weather Center in Norman will collaborate with IPHEx researchers and participate in Phases 2 and 3 of the planned hydrologic experiments. For Phase 2, we will provide a suite of NEXRAD-based precipitation, reflectivity, severe weather, and flash flood forecast products in real-time to be displayed on a web page for the IPHEx domain 3 (lat/lon extents are 32.69919N, -87.07486E and 38.70804N, -78.73277E). All these following products will be linked to a webpage for convenient daily downloads and archiving by participants and collaborators: Precipitation rates from NSSL's MultiRadar MultiSensor (MRMS) system at 1-km/2-min resolution, gauge-corrected hourly precipitation estimates (top of the hour), gauge-corrected daily precipitation estimates (1200 UTC), composite reflectivity, vertically integrated liquid water content, and forecast return periods at ungauged locations from the Flooded Locations and Simulated Hydrographs (FLASH) system at 1-km/10-min resolution. Note that the same web page will host real-time images of dual-pol images collected by the NOXP radar over the Pigeon basin. This latter dataset will need to be post-processed for research purposes in Phase 3.

During Phase 3, we will collaborate with researchers at the University of Connecticut and beyond to evaluate the hydrologic skill of contemporary precipitation forcings. This research will initially focus on the Pigeon river basin, but can also be expanded beneath the coverage of NPOL. The first objective will focus on the hydrologic utility of dual-polarization algorithms in reference to forcings from the NEXRAD-based MRMS system. Each radar-based quantitative precipitation estimate will be input to the calibrated and uncalibrated CREST model developed jointly by NASA and the University of Oklahoma (Wang et al., 2011). This will provide unique insights into the utility of gap-filling mobile radars in complex terrain, the impact of improvements from dual-polarization radars, as well as the prospects for hydrologic prediction in ungauged basins in complex terrain. In a forecast environment, these radar-observed forcings are useful for nowcasting, but offer little lead time to respond to impending flash flooding events. Thus, the second objective will focus on inputting quantitative precipitation forecasts from the ICLAMS model to be supplied by collaborators at UCONN to the calibrated and uncalibrated CREST model. Both objectives will quantify the hydrologic skill conditioned on the different forcings as a function of lead time, observed rainfall magnitude, basin scale, and calibrated vs. uncalibrated model. The anticipated research findings will help guide the expectations on the hydrologic utility of precipitation estimates from space in complex terrain.

Wang, J., Y. Hong, L. Li, J. J. Gourley, S. I. Khan, K. K. Yilmaz, R. F. Adler, F. S. Policelli, S. Habib, D. Irwin, A. S. Limaye, T. Korme, and L. Okello, 2011: The coupled routing and excess storage (CREST) distributed hydrological model. *Hydrol. Sci. Journal*, **56,** 84-98, doi: 10.1080/02626667.2010.543087.

E.2 Raindrop Fall Velocity Measurements during IPHEx Field Campaign

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Overview:
Clemson University researchers (Dr. Firat Testik and his graduate student) will participate to the IPHEx field campaign for approximately a week in May 2014. The exact dates will be determined based upon the short-term rain forecast to maximize the chance/amount of rainfall measurements during this time period and the availability of the instrumentation and the personnel.

Contributions:
We (Dr. Testik and his student) will contribute to the rainfall microphysical observations and their interpretations. We will conduct raindrop fall velocity measurements using our Advanced Disdrometer System (ADS). This system is an optical system with a high-speed camera. The ADS is optimized for accurate fall velocity measurements and can be used as a benchmark system for fall velocity measurements. We will provide measured fall velocity values in a data sheet in MS-Excel format. We will contribute to the scientific publications from the field campaign.

Logistics:
The ADS requires a power source and a dry space (for the operator and laptop) within 10 m of the measurement location. This requirement may be relaxed if a suitable vehicle with a mobile power generator can be arranged. Currently, we are working on this logistic issue. The exact location for the installment of the system and the logistic details will be determined after discussions with Dr. Barros. The graduate student will stay in the student housing provided for the field campaign participants. Details of the logistics will be finalized through discussions with Dr. Barros.